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PARTS, MATERIALS, AND PROCESSES EXPERIENCE SUMMARY

Volume I

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

N O T I C E

NASA SP-6507

PARTS, MATERIALS, AND PROCESSES EXPERIENCE SUMMARY

Volume I

Prepared under contract for NASA by
Lockheed Missiles & Space Company

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FOREWORD

Scientific and engineering organizations within the National Aeronautics and Space Administration, the Department of Defense, and throughout the aerospace industry are greatly concerned about the impact of system failures related to parts, materials, and processes. Establishment of the NASA ALERT reporting program in 1964, expanded in 1968 to include participants of the Government-Industry Data Exchange Program (GIDEP), provided the means for sharing and benefiting from each other's experience with these types of failures. Extensive data accumulated from ALERT reports have proved a valuable method of communicating problems and providing assistance in avoiding or minimizing recurrences.

In order that this accumulated experience be made readily available, this publication, *Parts, Materials, and Processes Experience Summary*, condenses and catalogs ALERT and other information on basic design, reliability, quality and application problems. Designers, engineers, failure analysts and other reliability and quality personnel will find the answers to many application and problem-avoidance questions.

This publication was developed under contract NAS2-6060 by the Lockheed Missiles & Space Company, Inc., Sunnyvale, Calif., under the leadership of W.L. Finch, W. Geller, and S. Ognibene. The contract was administered under the technical direction of NASA's Ames Research Center, Moffett Field, Calif., with G.E. DeYoung as technical monitor. This effort and the significant assistance provided by the members of the NASA Parts Steering Committee are gratefully acknowledged.

This issue of the *Summary* is a revision of CR-114391, Feb. 24, 1972. It includes, new, expanded, and revised material reflecting additional NASA experience and responses to the questionnaire sent to Government and industry personnel.

It is expected that this summary will be revised periodically to disseminate new and expanded information on existing topics and possibly new topics. Any suggestions or recommendations that will enhance its usefulness will be most welcome and should be referred to the Office of Safety and Reliability and Quality Assurance, NASA Headquarters, Washington, D.C. 20546.

GEORGE C. WHITE
Director, Safety and Reliability
and Quality Assurance

INTRODUCTION

OBJECTIVE

The objective of this *Parts, Materials, and Processes Experience Summary* is to provide the general engineering community with the accumulated experience from ALERT reports issued by NASA and the Government-Industry Data Exchange Program (GIDEP), and related experience gained by Government and industry. It provides expanded information on selected topics by relating the problem area (failure) to the cause, the investigation and findings, the suggestions for avoidance (inspections, screening tests, proper part applications, requirements for manufacturer's plant facilities, etc.), and failure analysis procedures.

ALERT PROGRAM

The ALERT program is a system for communicating common problems with parts, materials, and processes. The ALERT program has as its basic objective the avoidance, or at least the minimization, of the recurrence of parts, materials, and processes problems, thus improving the reliability of equipment produced for and used by the Government. An ALERT report is prepared when an item is believed to be in common usage and the problem may affect other users; copies are distributed to all participants in the ALERT program.

Information on the ALERT program may be obtained from the Office of Safety and Reliability and Quality Assurance, NASA Headquarters, Washington, D.C. 20546 (phone 202-755-2284); or from the GIDEP Administration Office, Fleet Missile Systems Analysis and Evaluation Annex, Code 862, Naval Weapons Station, Seal Beach, Corona, Calif. 91720 (phone 714-736-4677; Autovon: 933-4677).

ORGANIZATION OF SUMMARY

This two-volume publication is divided into 18 sections, one of which is a miscellaneous category. The other sections represent 17 major topics derived from the GIDEP major classification code. The GIDEP code number is shown on each section divider to assist in obtaining related data from test and qualification reports on parts and materials, scientific reports, technical information, manufacturing techniques, and specifications contained in the GIDEP file. Each section presents fundamental concepts followed by problems that have been experienced and suggestions for their avoidance; guidelines for producing good parts and materials; and procedures for determining why a failure occurred. Introductory remarks and a table of contents precede each section.

The 17 major topics (attaching methods, capacitors, transistors, etc.) were selected because they represent 82 percent of the ALERT reports issued by NASA and GIDEP through Aug. 31, 1972. The remaining reports are included through the medium of ALERT summaries in the miscellaneous section of Volume I.

ALERT ITEM NO.

Where appropriate within a section, each ALERT report has been assigned an "ALERT ITEM NO." in order to provide a cross reference between an ALERT referenced in the Problem/Screening Summary subsection and the same ALERT shown in the ALERT Summaries subsection.

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CODE FOR PROBLEM AREAS AND CAUSES

Some sections employ a coding system to identify the major problem areas and their causes. The code is entered in the Problem/Screening Summary subsections, on the assembly flow diagrams, and on the failure analysis flow diagrams. A separate foldout (Problem Codes and Definitions) defines the code used in a particular section of the publication. All foldouts are located in the appendix. The coding system ties together the problem area/cause, the preventive action, the critical process during assembly, and the failure analysis step. For instance within Section 3 (Capacitors), ALERT Item No. 7 in the Problem/Screening Summary subsection indicates a "Short" as the problem area, with the cause being "Breakdown of dielectric." Also shown are the suggested screens that should detect the problem area/cause. The foldout for Section 3 (Capacitors) establishes the problem code of the area/cause as "IID." This code in the Ceramic Capacitor–Typical Assembly Flow with Related Problem Codes diagram (fig. 3-2) indicates that "thin spots and contamination" during the "slip cast dry and roll green stock" operation can eventually cause a short because of dielectric breakdown. In a similar manner, the Ceramic Capacitor–Failure Analysis Flow with Related Problem Codes diagram (fig. 3-3) shows that the problem area/cause can be detected at the "radiographic inspection," or at the "depotting and examination" or the "dissection and examination" stages of the failure analysis procedure. The two diagrams can also be used in other ways. Possible problem areas/causes are depicted for any stage in the assembly operation, thus facilitating the creation of a process control check-off list. If the problem area is known, possible causes are shown for any stage in the failure analysis procedure.

REFERENCES

The title and responsible agency for a military standard or specification, or for a NASA special publication or handbook, are given in the list of references located at the back of the publication.

KEYWORD INDEX

Keyword indexing is provided in order to facilitate easy search and reference; e.g., an ALERT report for a particular relay may contain the words: "relay," "contamination," and "solder." Looking up those words in the index will lead to that particular relay problem; the words "contamination" or "solder" will also lead to other ALERT reports on other types of parts.

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Volume II

SECTION 1
ATTACHING METHODS
(GIDEP CODE 085)

CONTENTS

INTRODUCTION

Objective. The objective of this section is to identify the major problem areas associated with attaching methods and to provide approaches (developed from experience) for dealing with those problems.

Problem Definition. The problems are defined first by specific examples cited in ALERT reports, and then by using the broader data base of information available from other industry and government investigations. This section is limited to discussion on soldering and crimping.

Problem Prevention. Problem prevention is dealt with by providing relevant information with respect to tooling, operational techniques, design limits, and test/inspection criteria as applicable.

ATTACHING METHODS

Categories. Methods used for attaching hardware together may be grouped in three broad categories — thermally induced, chemical reaction, and mechanical operation.

Thermally Induced

Processes. This category includes brazing, soldering, and welding processes commonly used for both electrical and structural connections. Both brazing and soldering require addition of an intermediate alloy, while an intermediate alloy may or may not be used in welding. Principal distinguishing features of these three thermally induced processes are as follows.

Soldering and Brazing. Both soldering and low temperature brazing are surface solution processes which produce an intermetallic compound at the interface between the filler material alloy and parent materials. Maximum temperatures employed are below the melting point of the parent materials. As defined by the American Welding Society, "brazing" applies to a "soldering" process if the melting point of the filler material exceeds 800°F (427°C).

There is metallurgical evidence, however, that many higher temperature brazing processes do in fact produce results indicating that temperature, localized to the interface between the parent materials, has in fact exceeded the melting point of the parent materials.

Welding. This is a fusion process which requires local temperatures above the melting point of the parent material, resulting in an intimate fusion of both parent materials. In certain welding processes additional material is added in the area to be joined, while for other processes the parent material is used alone.

Defective Joints. Common causes of workmanship defects in thermally induced joints are inclusion of contaminants and inadequate process control (principally time and temperature). Common design problems are inadequate provision for thermal and mechanical stresses and materials incompatibility.

Chemical Reaction

Bonding. This method is the principal reaction that is used as an attaching method for hardware parts. It normally consists of mixing and curing of two or more compounds to form a chemical structure that molecularly attaches (bonds) to the surface of the materials to be joined. Some so-called one part bonding systems, such as RTV elastomers, use airborne moisture or oxygen as the second compound required for formation of the bond.

Defective Bonds. Most defective bonds are caused by entrained contaminants, including improperly prepared surfaces, and/or inadequate process control with respect to mixing, curing, temperature, and time.

Mechanical Operation

Processes. Mechanical operation includes the crimping, swaging, riveting, and wire-wrap procedures that deform a metal past its elastic limit. The deformation may be compression in one plane or elongation. The required force may be applied directly to the parent material (as in crimping and swaging), or to an added fastener as in riveting and wire-wrap. Control of the deformation rate and extent is required to preclude fractures.

Defective Attachments. Common causes of inadequate mechanically created attachments include use of improper tooling and/or techniques. An example of an improper technique is swaging with the wrong mandrel speed and/or pressure. Either of these can result in radial fracture (splitting) instead of the desired plastic deformation of the metal which produces a satisfactory swaged joint.

OVERSTRESS

Result of Overstress. Not to be ignored in any listing of failure mechanisms for attaching methods is application of excessive stress. This is primarily caused by inadequate design and should be detected by testing. An insidious form of overstressing often overlooked is thermal stressing due to incompatibilities of coefficients of thermal expansion. This can result in crystallization of solder connections by cold working. Cold work crystallization of solder connections can be first detected as abnormal bulging and/or stretch lines on the surface (Luders' line).

PROBLEM AREA/CAUSE AND SUGGESTED ACTION

Problem areas and causes associated with soldering and crimping are shown below. Suggested actions for minimizing the problems are indicated as applicable. The "ALERT ITEM NO." relates each entry to the summaries of ALERT reports which are presented in the last portion of this section.

SOLDERING

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
CRACKED SOLDER CONNECTIONS Thermal stress fatigue	1,2,3	Design to minimize thermal expansion mismatch of materials
POOR SOLDER CONNECTIONS Lack of antimony content	4	Periodic analysis of incoming solder lots
SOLDER SHELF LIFE Core deterioration	5	Seal (by crimping) end of wire after use

CRIMPING

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
BROKEN WIRE Wire insulation in terminal barrel	6	Preclude insertion of insulation by: (1) use of adequate wire/barrel diameter ratio, (2) shop instruction, or (3) stop on crimping tool
BROKEN WIRE Excessive crimping pressure Mislocation of crimp indent	7 8	Use crimping tool certified for applicable wire type and size
DEFORMED AND/OR SEVERED WIRE Wrong crimping tool	9	Use crimping tool certified for applicable wire type and size
POOR CRIMP CONNECTION Inadequate tooling	10	Avoid use of crimped connections when available tools are not certified

SOLDERING

DISCUSSION

Cracked Solder Connections. The first three entries on the summary table describes solder connections cracking because of thermal fatigue. These failures can be reduced by applying and controlling appropriate design criteria. Unfortunately, it is difficult to distinguish between solder cracking as a result of thermal fatigue and solder cracking because of poor workmanship (cold solder connections) in an after-the-fact investigation. The principal difference is as follows.

Workmanship vs Thermal Fatigue. Solder cracks resulting from poor workmanship will appear at random locations on sequentially manufactured articles. Thermal fatigue induced cracks will occur in a predictable repeating location on sequentially manufactured articles when the articles are subjected to the same environment. Furthermore, thermal fatigue induced cracks will propagate with storage time because of minor thermal variations. Prior to rupture and after limited exposure to thermal variations, solder connections that have been stressed by the mismatch of adjacent materials thermal expansion (thermal fatigue) will exhibit bulging and/or stretch lines on the surface (Luders' line). On the other hand, cold solder connections (caused by poor workmanship) will display no changes in surface condition and will retain their relatively smooth, dull, nonsatiny finish when thermally cycled - provided the adjacent materials are minimally matched with respect to thermal expansion.

Crystal Growth. The change in surface conditions of a connection being thermally fatigued is caused by localized interior "crystal" growth. This solder structure change results from cold working by forces generated by differential expansion/contraction of adjacent materials. Therefore, the bulges and/or stretch lines on the surface (Luders' line) reflect a nondesirable anisotropic interior solder structure.

Swaging. One of the more common occurring sources of thermal fatigue induced cracks in solder connections is soldering a swaged brass terminal to both sides of a double-sided printed wiring board. The differential expansion/contraction of the brass solid (Coef Expansion 18 X 10^{-6} in/in/°C) and epoxy-glass board (Coef Expansion 60 X 10^{-6} in/in/°C) is sufficient to produce cracks in less than 100 cycles with a temperature range of 155°C. The known conditions that contribute to this type of failure should be supplied to the designer as mandatory criteria. A partial list is included in this section under "Design Criteria to Minimize Solder Connection Problems" which follows.

Material Problems. The other two entries on the summary table describe failures caused by material properties of solder and are amenable to normal quality control by design/application engineering restraints.

NOTE: See NASA SP-5002, Appendix C (ref 1) for more detail on solder cracking

DESIGN CRITERIA TO MINIMIZE SOLDER CONNECTION PROBLEMS

The following list of design criteria is provided as a suggested guide for designers. The term "printed wiring board" includes "multilayer board" for purposes of this criteria.

1. Do not use rigid encapsulating systems to secure and/or protect solder connected parts on printed wiring boards.

2. Use only silicone or polyurethene based conformal coatings.

3. Conformal coatings should be held to minimum thickness.

4. If connections are required on a double-sided printed wiring board for one metallic part such as lead or terminal, space one solder connection 1/8 inch or more from edge of the feed-through hole or use a redundant hole for the terminal or lead. Fill all feed-through holes with solder. Feed-through holes should be plated.

5. Resilient spacers, when used, should be of minimum thickness between any solder connected part and printed wiring board.

6. Do not hard mount parts to printed boards with mechanical fasteners or similar devices unless leads are parallel to the board and of such length as to provide for strain relief.

7. Do not hard mount parts to printed wiring boards by using minimum lead length inserted through feed-through holes and soldering it to the opposing end of plated-through hole. Always provide strain relief in the part lead.

8. Avoid cordwood construction for solder connected assemblies unless strain relief is provided in one part lead (axial part lead between printed wiring boards).

9. Avoid gold-plated boards. Use solder-plated or solder-coated boards. Require sample solder tests to be conducted on each lot of boards.

10. Use terminals only when necessary and then only use terminals designed to be used on printed wiring boards. A funnel type swage should be used to secure the terminal to the board.

Note: See following sources for additional information

1. AHB 5332-1, "Soldering Students Handbook"
2. MSFC-STD-136, "Parts Mounting Design Requirements for Soldered Printed Wiring Board Assemblies"
3. TM X-2290, "Solder-Circuitry Separation Problems Associated with Plated Printed Circuit Boards"
4. TM X-53653, "Investigation of Solder Cracking Problems on Printed Circuit Boards"
5. TM X-53731, "Mounting of Components to Printed Wiring Boards"

CRIMPING

Broken Wire. The first item on the summary table under crimping, broken wire because of insertion of insulation into terminal pin barrel, is subject to attack at both the engineering and manufacturing level. The designer should be supplied with a complete listing of applicable wire insulation outer diameter dimensions and barrel and/or ferrule inner diameter dimensions in such a form that will facilitate selection of combinations of wire/connectors that cannot be mismated in the above fashion. Shop personnel should be informed by appropriate written instructions and/or visual aids that insertion of insulation into pin barrels and/or ferrules prior to crimping is forbidden.

Use of Improper Tool. The remaining four items have a common cause - use of improper tool. In one case, the problem was compounded by engineering requirement to use materials in a manner for which required tooling was not known.

Tool Qualification. Proper tools for crimping each wire/connection should be positively identified by qualification before incorporation into any design. To assure the repeatability of each different wire/terminal crimping, each tool should be periodically submitted for qualification testing and/or calibration as required. Both engineering and manufacturing should be supplied with a list of all approved crimping tools that includes wire/terminal combinations that may be crimped with each tool. These lists should be periodically updated to include changes in tool status and/or application of crimping tools.

Tool Identification. Intermittent misapplication of crimping tools because of shop negligence can be reduced by color coding tools and shop orders or supplies (wire and terminals).

ALERT SUMMARIES

Summaries of ALERT reports issued against Soldering and Crimping problems are shown below. They are listed according to Problem Area - most frequent to least frequent occurrences. The "ALERT ITEM NO." (first column) references each summary back to the "Problem Area/Cause and Suggested Action" table.

SOLDERING

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
1 MSFC-66-05, Add 1, 2	CRACKED SOLDER CONNECTIONS Thermal stress fatigue	Cracked solder connections were discovered on printed wiring boards. Severity of the problem increased with time and temperature cycling.	Investigation revealed that the cracking was caused by stress accumulation created by incompatibilities of coefficients of expansion between adjacently used materials. Materials of concern included rigid potting, printed wiring board material, feed-through eyelets, transistor cases, component standoffs, lead wires, etc. and synergistic effects of configuration and mounting procedures.
2 C6-69-01	CRACKED SOLDER CONNECTIONS Thermal stress fatigue	Cracked solder connections were discovered on printed wiring boards.	Cracking was attributed to repeated stresses imposed on the solder connection by differential thermal expansion of the assembly during ambient or operating temperature cycling.
3 C6-69-02	CRACKED SOLDER CONNECTIONS Thermal stress fatigue	Solder connections cracked in modules potted in epoxy, silicone, or urethene.	Investigation of different potting compounds showed that the lowest incidence of cracking of solder connections was with a potting compound with a very low coefficient of thermal expansion. Whenever possible, modules should be designed so that potting is not required for structural integrity. Instead, use a relatively thin conformal coating. Avoid any configuration that would allow a build-up, or pocketing, of conformal coating under the parts. If potting must be used, select a material with a very low coefficient of thermal expansion. All parts should have strain relief in their leads. Avoid soldered cordwood types of module configurations.
4 KSC 12-5-65, Supl 1	POOR SOLDER CONNECTIONS Lack of antimony content	Difficulty was encountered in obtaining satisfactory solder connections.	Sample coupons exhibited poor flow characteristic and dull, grainy texture. Spectrographic analysis revealed that antimony content was 500% below specification requirements.
5 S6-69-01	SOLDER SHELF LIFE Core deterioration	A silver bearing tin-lead solder, with a proprietary core flux, deteriorated when held in storage	Investigation revealed cause to be deterioration of flux when exposed to air. A partial solution was to unroll and discard outer layer of solder on roll, thus exposing usable solder.

CRIMPING

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
6 ARC 10-21-66	BROKEN WIRE Wire insulation in terminal barrel	Repeated failures were observed on size AWG 22 and 24 wire with crimp type connectors.	Investigation revealed that insertion of conductor insulation into pin barrel crimp area reduced life expectancy of connection. Some failures were observed after one flexing.
7 KSC 5-22-64	BROKEN WIRE Excessive crimping pressure	Cables being made with connectors and hard wire (nickel-clad) exhibited broken wires at terminations.	Investigation revealed cause was due to use of wrong crimping tool due to inadequate tool qualification and/or maintenance.
8 C6-71-01	BROKEN WIRE Mislocation of the crimp indent	Damaged and/or broken connector contacts and wire strands were observed that were due to a longitudinal variation in location of the crimp indent.	In some cases, indent fell at the end of contact shell; in others, was placed in wire insulation. Both conditions could result in connection malfunction. Problem solved by use of proper tool which included a positioner.
9 C1-70-01	DEFORMED AND/OR SEVERED WIRE Wrong crimping tool	Crimping tool caused excessive deformation and/or severence of conductors.	Tool qualified for polyvinyl chloride (PVC) insulated wire used on TFE insulated wire. TFE is less easily deformed than PVC. Therefore, more force was exerted on the TFE insulated conductor. This resulted in the deformation or fracture of the conductor which resulted (in some cases) in latent open circuits.
10 L9-69-04	POOR CRIMP CONNECTION Inadequate tooling	Numerous resistive connections were observed between connector pin and wire, which were sometimes intermittent in nature.	Crimp connections were made using No. 26 AWG silver plated copper, solid conductor wire. Connector manufacturer could not supply or identify crimping tool which could make satisfactory connections.

NOTE:
1. Where no ALERT number (GIDEP) exists, the originator and date are shown.

SECTION 2
BATTERIES
(GIDEP CODE 101, 102)

CONTENTS

INTRODUCTION

OBJECTIVE

The objective of this section is to identify the major problem areas associated with the use of nickle-cadmium and silver-zinc batteries and to suggest approaches (developed from experience) for dealing with those problems.

SECTION ORGANIZATION

The battery section is presented with the following organization:

General

1. Basic failure problems associated with batteries are identified based upon ALERT and industry experience.

2. Where applicable a screening technique is suggested for detecting finished parts having a potential for failure.

Subtopics - Treatment of Specific Types

1. Battery type background

2. For those in the process of selecting batteries, or attempting to eliminate part problems at the manufacturer levels, a portion is devoted to describing general construction features. Particular emphasis is given to the design or manufacturing deficiencies associated with the identified failure mechanism.

3. Basic approaches are provided to assist in developing a competent failure analysis plan. The material is arranged so that one experiencing a specific problem can identify those steps in the failure analysis process likely to reveal that problem.

Battery Types. Batteries have been divided into subtopics according to electrochemical system. This section deals with two systems, silver-zinc and nickel-cadmium. An attempt is made to point out common properties of batteries as well as the peculiarities of each system.

BATTERY FUNDAMENTALS

What a Battery Should Do. A battery is a storage device for electrical energy and is made up of one or more battery cells usually connected in series, so it is valid to discuss the properties of a single cell. Each cell contains one or more positive and one more negative electrodes (or plates) in parallel; therefore, its no current or open circuit voltage is determined by the electrochemical potential of that positive and negative electrode couple. The reproducibility of the open circuit voltage, OCV, is a function of the electrochemical system rather than peculiarities of cell design and consequently is a useful diagnostic tool.

When a resistance is placed across the cell terminals its voltage, or potential, will drive current through the load. Cell voltage will drop for two reasons, first, due to drop across the internal resistance, and secondly, because of internal inefficiencies. The result is a unique voltage-current relationship for each cell at a given temperature. Since temperature is such a great factor in battery performance and life, batteries are usually specified for limited temperature ranges.

Ideally a battery cell only discharges when a circuit is closed across its terminals. Unfortunately, depending on the system, there may be self-discharge or loss of stored capacity when at open circuit.

In speaking of energy storage, the battery cell stores electrons at a given potential. Electrons are equated to ampere-hours and potential is equated to volts. The battery designer uses ampere-hours to calculate the amount of active material which must be on the electrodes.

There are two broad classifications of batteries, primary and secondary. Primary signifies one-shot and secondary signifies rechargeable use. A rechargeable battery is dependent on a charging source which, if improperly controlled, can cause battery failure. Failure analyses of secondary batteries should consider the charge controller.

Practical Considerations. A battery cell is by its nature an active device in the sense that once electrolyte is added it is irreversibly activated, which means it has the electrochemical potential to release power and the corrosion potential of its strong caustic or acid electrolyte. The cell differs from most parts in that it has the potential for self destruction and is a limited life item. In order to build lightweight and compact batteries without giving up performance, margins of safety are closely designed and this imposes close control requirements on manufacturing processes and user limitations.

Nickel-Cadmium Battery Background. Sealed Ni-Cd cells have been used extensively in applications requiring long life and thousands of charge-discharge cycles without maintenance. These batteries are found in communication satellites as well as home appliances. Vented Ni-Cd batteries are used in ground and aircraft applications where high performance is desired and routine maintenance is practicable. The vented cells expel hydrogen and oxygen, consuming water which must be periodically added. A chief attribute of this battery is its high rate capability. The Ni-Cd cell is relatively stable chemically allowing long life and high reliability; however, the high production commercial cells have neither the same quality nor design features of aerospace cells. Stainless steel cell cases are usually used.

Silver-Zinc Battery Background. These batteries are noted for high energy density and have been used extensively in aerospace applications. Up to 120 watt-hours per pound has been attained in large, low rate primary batteries. Ag-Zn secondary batteries are increasing in use, but their use in that mode is limited by number of cycles, depth of discharge, and calendar life.

The Ag-Zn system is chemically less stable than the Ni-Cd. Zinc and silver oxide have a limited solubility in potassium hydroxide electrolyte; the zinc and electrolyte form hydrogen gas which is vented and the silver oxide yields silver ion which slowly oxidizes the cellulosic separation. Pinholes in the separator film eventually allows a silver bridge to form shorting the cell. This mode of failure is well known and life is predictable. Applications should be carefully evaluated before the system designer decides on using a Ag-Zn battery. Vented plastic cell cases are usually used, although development of sealed cells is continuing.

FAILURE MODES

Failure Categories. Part level failure problems associated with batteries may be lumped under four basic categories: catastrophic shorts, catastrophic open circuit, deviations in electrical performance, and mechanical anomalies. A common mechanical anomaly is leakage from a cell seal. System level failures in charge control or thermal design, while not caused by the battery, may be falsely interpreted as a defect in the battery.

False Failed-Equipment Indicators. On a system level low voltage may be due to a short outside of the battery or improper charging, but generally, reported battery anomalies prove to be valid.

ELIMINATING DEFECTIVES

Problem Solving Approach. The approach taken in this section will be to identify the user encountered problem areas associated with nickel-cadmium and silver-zinc batteries, then provide suggestions for eliminating failed or failure prone units at the finished, manufacturing, and design level.

Finished Battery Level. Suggestions are offered on the shipping, handling, and testing of batteries prior to application for two purposes. First, to screen failed or failure prone units, and secondly, to assure the unit is not degraded by improper treatment.

Design Level. While screening has proven highly effective, it does not compensate for design compromises and/or deficiencies. Battery design involves compromising one feature for another, such as life versus internal resistance; however, reliable equipment can be built if design tolerances can be based on established practice or valid test data.

Manufacturing Level. Many of the specialty type, noncommercial batteries are manufactured using considerable hand labor. Most of the assembly operations are very repetitious while requiring great care. Consequently, low skilled people are trained for these tasks. This imposes a high premium on close controls over materials, processes, and workmanship. As no screening is totally effective, it is desirable to correct manufacturing anomalies through the use of adequate controls and inspection points.

FAILURE ANALYSIS

Objective. A primary objective is to identify failure mechanisms and relate them to a design deficiency or error in manufacture, handling, or system application. New designs are frequently dictated by failure rather than by innovation.

Failed Part Rarity. Failed parts are rare and offer a unique opportunity for learning. In the case of a battery, prompt reaction to reported anomalies is critical since continued chemical action and heat (as in a short) may destroy the evidence. This also prescribes complete data records of the anomalous behavior, since frequently the hardware may not be available or susceptible to physical examination.

Failure Verification. After recording all data of the reported anomaly and external examination of the battery, the first requirement is to verify the failure and carefully document all attendant circumstances.

Analysis Direction. The process of analyzing a failure, performing those steps necessary on a suspect device which will result in the identification of a specific correctable failure mechanism, requires the coordination of a series of specialized skills by one having knowledge of failure mechanisms, device design, and manufacturing techniques; and the experience necessary to organize this combination of skills and knowledge into a practical plan of action.

When to Analyze. Many part failures occur for which no corrective action is planned to be taken. In many cases it is most cost effective to simply scrap the defective part and replace it with one that performs properly. For those cases where it is necessary to have assurance that future failures will not occur, a portion of this section is devoted to describing some of the considerations involved in performing effective failure analysis.

Reliability/Life. It is anticipated that as a result of this series of actions at the part level (screening, analysis of design and manufacturing, and effective failure analysis) that significant improvement in reliability and life will be realized.

PROBLEM/SCREENING SUMMARY

Scope. This problem summary subsection is a compilation of problem areas derived from the ALERT reports and the wide experience acquired over years of such encounters. It does not presume to list all possible problem areas/causes possible within Ni-Cd or Ag-Zn batteries, but is an attempt at compiling the most commonly encountered problems. To avoid confusion these two battery types are treated independently.

ALERT Item No. Where directly applicable, the "ALERT Item No." of the ALERT report describing a specific cause for a failure is listed against that cause. Thereby a cross reference is provided between a specific failure cause found in the "Alert Summaries" and the broader failure experience/avoidance knowledge shown in this presentation.

The problems have been categorized into the following principal areas:

1. Open Circuit
2. Short Circuit
3. Operational Deviation
4. External Anomaly

PROBLEM AREA/CAUSE AND SUGGESTED ACTION

NICKEL-CADMIUM BATTERIES

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
OPERATIONAL DEVIATION Improper process control	1	Electrical Performance Test
SHORT CIRCUIT Design deficiency	2	Mechanical Characteristics and Lot Sample Destructive Tests
OPERATIONAL DEVIATION Design deficiency	3	Mechanical Characteristics, Open Circuit Decay and Pin-to-Case Voltage Tests

SILVER-ZINC BATTERIES

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
OPEN CIRCUIT Design deficiency or material incompatibility	4	Lot Sample Destructive Test
SHORT CIRCUIT Manufacturing fault	5	Open Circuit Voltage Decay Test
OPERATIONAL DEVIATION Design deficiency	6	Electrical Characteristics and Temperature Measurement Test
EXTERNAL ANOMALY Design deficiency	7	Visual Examination
EXTERNAL ANOMALY Uncontrolled shipping environment	8	Visual Examination and Electrical Performance

SCREENING INSPECTIONS AND TESTS

Basic Screening. The screening inspections and tests suggested for batteries included in the Problem/Screening Summary are as follows:

1. Visual Examination
2. Electrical Performance
3. Mechanical Characteristics
4. Seal Integrity
5. Pin-to-Case Voltage Checks
6. Open Circuit Voltage Decay
7. Electrolyte Volume and Analysis
8. Lot Sample Destructive Tests
9. Temperature Measurement

Objective. The above tests have evolved from the attempt to do everything possible to assure reliable performance. Slight anomalies and trends of measurement are sought as indicators of worsening conditions since battery failures usually develop over a period of time.

Additional Screening. Specific battery designs may dictate added tests or provide instrumentation for monitoring parameters such as temperature and pressure.

1. VISUAL EXAMINATION

Visual examination of battery cells and batteries at the manufacturer's facility is recommended for indications of faulty workmanship and to insure strict conformance to interface requirements. Of particular concern in vented Ag-Zn cells is adequate insulation of terminals and intercell connectors from potential electrolyte leakage. Note that this may not be a problem in conventional ground applications.

2. ELECTRICAL PERFORMANCE

In any battery there are two main criteria of electrical performance, capacity and voltage regulation. Primary batteries present a problem in measuring capacity since a unit cannot be recharged; therefore, lot sample cells must be used for a statistical prediction. Secondary batteries can be repeatedly charged and discharged under varied conditions to develop confidence and allow infant mortality to occur, since cells with gross defects should show symptoms of deficiency. Furthermore, if cells of matched capacity are desired, as in long life applications, cells at high and low extremes may be rejected although within nominal specifications.

Voltage regulation is used to monitor cell health under open circuit and load. Open circuit is very meaningful in Ag-Zn batteries since it is stable at both oxide levels of silver, although the transition phase is indecisive. At either voltage "plateau" a decay in open circuit voltage is indicative of a short or curtailed capacity. For that reason and the need for a "soak-time" to saturate separators and electrodes, open circuit readings may be taken over many hours to note any decay.

Ni-Cd cells may use voltage for charge control and certain Ni-Cd cells are equipped with auxiliary electrodes for this function and for recombination of oxygen with cadmium or oxygen with hydrogen. The subject of auxiliary electrodes is complex and usually peculiar to each manufacturer; therefore, we will only state that once auxiliary electrode performance is characterized for a cell it can be a valuable control and diagnostic tool. Open circuit voltage measurements should always be made with a high-impedance voltmeter to avoid "loading down" a battery.

3. MECHANICAL CHARACTERISTICS

These measurements and checks are made to verify compliance of cells and batteries to all physical interface requirements such as weight, dimensions, case finish, name plate designations, and connector and wiring configurations.

4. SEAL INTEGRITY

Ag-Zn Batteries. This cell is usually vented or equipped with a relief valve, since hydrogen and some oxygen is liberated during the life of the cell. Seals are important to contain electrolyte and prevent shorts. A good method for checking seals is achieved by using vacuum activation of cells. Where closed battery cases equipped with relief valves are used the seals are commonly checked using pressure retention measurements; helium leak checks are not merited since the battery generates gas and small leaks are not likely to be deterimental.

Ni-Cd Batteries. This cell is available in vented or sealed form. The sealed cell, depending on size and requirements, can come with varied seal designs. The design dictates practical limits on test methods. Chief concern develops in long-life and frequently charged cells where low helium leakage rates are specified. Extensive R&D has gone into high quality ceramic-to-metal terminal seals which isolate the terminal from the usual stainless steel cell case.

Checking of cell case welds and seals is done conveniently during manufacture, but screening tests for seals are limited since leaks may develop over extended periods. Old cells are frequently seen with potassium carbonate formed around terminal seals; this condition may exist with no apparent effect on performance. Phenolphthalein is frequently used as an indicator on caustic seals.

5. PIN-TO-CASE VOLTAGE CHECKS

Battery connector pin (positive and negative) to case checks for voltage are an excellent way of detecting electrolyte or condensed water paths from the battery circuit to structure or case. The grounding of battery cases to general equipment structure enables in-place or remote checkout.

6. OPEN CIRCUIT VOLTAGE DECAY

This test is chiefly addressed to Ag-Zn batteries and is briefly discussed under 2. above. The essence of this test is that electrochemical potentials of single species electrodes surfaces are predictable and are independent of cell design variables. Care must be taken in establishing criteria of acceptable versus unacceptable voltages, since decay of a voltage is more significant than absolute value. Accuracy demands that individual cell voltages be monitored as over-all battery voltage may mask any significant effects. The 1.85 and 1.595 values for the silver peroxide and oxide levels respectively are well remembered values to Ag-Zn users.

7. ELECTROLYTE VOLUME AND ANALYSIS

This paragraph is chiefly related to Ag-Zn batteries where electrolyte is not added to the cell (activation) until it is ready to be used. Electrolyte is most reliably packaged by the manufacturer and shipped with the battery. If one or more test cells accompany the battery, it is possible by a cell performance test to find fault with either the cell or the electrolyte.

8. LOT SAMPLE DESTRUCTIVE TESTS

As a means of either acceptance testing a battery or establishing reliability data on mean-time-to-failure, there are extra cells from each lot built for destructive test.

9. TEMPERATURE MEASUREMENT TESTS

Any deviations from expected operating or environmental temperatures are suspect and require rationalization. Excess heat can usually be attributed to short or improper charge control, for a Ni-Cd battery.

ALERT SUMMARIES

Summaries of ALERT reports issued against Batteries are shown below. They are listed according to type of battery.

NICKEL-CADMIUM BATTERIES

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
1 GSFC-68-11	OPERATIONAL DEVIATION Improper process control	Cells tested approximately 0.1 volts higher than normal and abnormally high pressures resulted during low rate overcharge.	Gas analysis revealed the pressure rise was caused by the accumulation of hydrogen in the test cells. No oxygen was being generated during the overcharge. Causes of the problem are attributed to improper formation of plates, poor control of impurities in water used to wash plates, and impurities/contaminates in separator material. The problem is most critical at low temperatures.
2 GSFC-69-15	SHORT CIRCUIT Design deficiency	Battery pack used with wire-wrap tool overheats during charging.	Failure analysis revealed the cause as insulation abrasion, wear through, and short circuiting. The eventual short circuiting is caused by repeated plugging of the pack into a charging source or by the normal vibration in use of the pack since the pack serves as a tool handle. The batteries should not be charged in a horizontal position.
3 KSC-68-02, MSC-68-02	OPERATIONAL DEVIATION Design deficiency	Several camera capsule control units malfunctioned during systems test as a result of failure to exhibit proper voltage levels.	Failure analysis revealed leakage of electrolyte through thin epoxy walls of battery case, through polyurethane foam potting around battery, and corrosion and short circuiting of circuit board and relay circuits. Cracks in the potted epoxy case surrounding the cells allowed electrolyte to pass out to adjacent electronic equipment.

SILVER-ZINC BATTERIES

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
4 LaRC-69-01	OPEN CIRCUIT Design deficiency or material incompatibility	On two separate launch attempts, a total of three batteries failed to activate when commanded.	Failure analysis revealed that the gas generator cartridge which forces electrolyte into the cells had failed to operate. Disassembly of the cartridges showed the bridge wires within the matches were open from application of firing current and matches were otherwise intact. Failure mode was identified as the inerting of the match by the chemical reaction of nitroglycerine of the N5 propellant and the LMNR base of the match squib.

SILVER-ZINC BATTERIES

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
5 MSC 6-8-65	SHORT Manufacturing fault	Battery showed a terminal voltage drop.	Failure analysis revealed one cell had a low open circuit voltage. Trouble was isolated to a plate having a shorted area. Chemical analyses of the material in the shorted area revealed no foreign materials. Failure was attributed to the protruding portion of one of the two plates, such as a burr, having punctured the separation material.
6 MSFC -68-17	OPERATIONAL DEVIATION Design deficiency	Thermostat cutoff at 86°F instead of the specified 105 ±15°F.	Failure analysis revealed the thermostat was imbedded in foam instead of next to the cells. Also, the terminals of the battery cell selector were mislocated too close to the case.
7 KSC 3-30-67, Addendum	EXTERNAL ANOMALY Design deficiency	Radial cracks (hairline) at the filler ports were discovered during battery activation, first indication was fluid seepage.	Failure analysis confirmed cracks or crazing of filler ports on seven batteries. Pressure leak tests substantiated the severity of the cracks seen under the microscope. The cracks were attributed to internal stress build-up as a result of the drilling and threading of the plexiglass filler neck buttons. Crazing was accelerated by the cementing of the filler neck buttons to the battery cell lids.
8 E9-A-72-04	EXTERNAL ANOMALY Uncontrolled shipping environment	Inspection of nonactivated battery showed buckled plates and deformed vent valves	Investigation revealed the damage was caused by excessive temperatures encountered inside truck vans during shipment.

NOTE:
1. Where no ALERT number (GIDEP) exists, the originator and date are shown.

3

SECTION 3
CAPACITORS
(GIDEP CODE 153,161)

CONTENTS

INTRODUCTION

OBJECTIVE

The objective of this section is to identify the major problem areas associated with the use of capacitors and to suggest approaches (developed from experience) for dealing with those problems.

SECTION ORGANIZATION

The capacitor section is presented with the following organization:

General

1. Basic failure problems associated with capacitors are identified based upon ALERT and industry experience.

2. Where applicable, a screening technique is suggested for detecting finished parts having a potential for failure.

Subtopics - Treatment of Specific Types

1. Capacitor type background.

2. For those in the process of selecting parts and manufacturers or attempting to eliminate part problems at the manufacturer levels, a portion is devoted to describing the inner construction of selected types and describing the manufacturing sequence necessary to produce the part. Particular emphasis is given to the design or manufacturing deficiencies associated with the identified failure mechanisms.

3. Basic approaches are provided to assist in developing a competent failure analysis plan where corrective action at the part level is desired. The material is arranged so that one experiencing a specific problem can identify those steps in the failure analysis process likely to reveal that problem.

Capacitor Types. Capacitors have been divided into subtopics according to their internal construction. Ceramic, solid tantalum, wet-slug tantalum, and glass capacitors have been discussed in depth. Other subtopics dealing with mica capacitors, tantalum foil capacitors, etc. include only summaries of ALERT reports.

CAPACITOR FUNDAMENTALS

What a Capacitor Should Do. Capacitance is a basic electrical circuit parameter representing the ability of a circuit to store an electrical charge with respect to the applied voltage. Capacitors are devices constructed to provide known amounts of capacitance to circuits in order to fulfill electrical design requirements. In its fundamental form, a capacitor consists of two conductive materials (plates) separated by a nonconductor (dielectric). Its capacitance is related directly to the product of the dielectric constant of the nonconductor and the area of the plates and inversely to the thickness of the dielectric material separating the plates. The dielectric constant of a material is determined empirically by relating to that value associated with vacuum (i.e., 1).

Practical Considerations. Analysis indicates that, because of physical imperfections in materials and laws that govern their properties, a capacitor cannot simply be defined by its capacitance value. Physical considerations force us to recognize such compromising characteristics built into a capacitor as dielectric breakdown voltage, dc leakage (insulation resistance), dissipation factor (equivalent series resistance), temperature coefficient of capacitance, induced voltage effects, and frequency effects. It is only by recognizing and controlling all of these factors that stable, reliable capacitors can be developed and manufactured. The latter two of these characteristics, voltage and frequency effects, are established by the nature of the dielectric and the other materials used in the construction of the device, and are dealt with as application limitations. The remaining factors are the ones usually associated with capacitor failure.

FAILURE MODES

Failure Categories. Part level failure problems associated with capacitors may be lumped under four basic categories: catastrophic opens, catastrophic shorts, electrical parameter deviation, and external mechanical anomalies. It must be recognized that catastrophic opens and shorts are worst-case conditions of certain electrical parameter deviations.

False Failed-Equipment Indicators. At the equipment level, low capacitance can appear to be an open, and high dc leakage (low insulation resistance) may appear to be a short. A failure mechanism producing an apparent open or short (e.g., a parameter deviation), in its extreme condition, becomes an open or a short. Failure analysis must be made at the part level in order to distinguish between these conditions and proceed to a corrective action.

ELIMINATING DEFECTIVES

Problem Solving Approach. The approach taken in this section will be to identify the user-encountered problem areas associated with a particular type of capacitor, then provide suggestions for eliminating those capacitors prone to exhibiting these problems at the finished capacitor level, the design level, and at the manufacturing level.

Finished Capacitor Level. Recognizing that the typical consumer is faced with using finished devices that are on-hand, information is provided for screening — sorting the bad ones from the good. Suggestions are made for subjecting the capacitors to environmental stresses (capable of identifying defective units, but well within the safe operating margins for properly made units). This reliability technique has found use not only for sorting, but for providing assurance that the manufacturer has controlled his processes.

Design Level. While screening has proven to be an effective reliability tool, it does not correct the fundamental problems of design compromises and worse yet — design deficiencies. Certain design compromises are inevitable, however, reliable equipment can be built if these compromises are recognized, and proper precautions are taken in the equipment design to minimize the effects of these compromises. Design deficiencies must be identified and eliminated at the manufacturer's facility.

Manufacturing Level. The most carefully conceived design can be brought to nought if it is manufactured in an environment lacking necessary controls over critical materials and processes, and allowing substandard workmanship. Again, defectives produced as a result of these conditions can be removed using a screening, but since no screen is 100 percent effective, a more desirable technique for removing these potential reliability degraders is to take action to correct these manufacturing conditions by applying controls and providing inspection points.

FAILURE ANALYSIS

Objective. A primary objective of failure analysis is to identify failure mechanisms at a level such that corrective action is feasible. Knowing nothing more about a capacitor than that it is shorted does not allow effective corrective action. If we learn that the short is caused by silver migration, we now have identified a mechanism suitable for corrective action. The silver can be eliminated, or the conditions that enhance migration can be controlled.

Failure Verification. After recording all identifying external markings, and performing a thorough external and radiographic inspection, the first requirement is to verify the failure. Too often the wrong part is removed from the circuit or an equipment test error, rather than a part failure, results in a good part being delivered for failure analysis.

Analysis Direction. The process of analyzing a failure, performing those steps necessary on a suspect device which will result in the identification of a specific correctable failure mechanism, requires the coordination of a series of specialized skills by one having knowledge of failure mechanisms, device design, and manufacturing techniques; and the experience necessary to organize this combination of skills and knowledge into a practical plan of action.

When to Analyze. Many part failures occur for which no corrective action is planned to be taken. In many cases it is most cost effective to simply scrap the defective part and replace it with one that performs properly. For those cases where it is necessary to have assurance that future failures will not occur, a portion of this section is devoted to describing some of the considerations involved in performing effective failure analysis.

Reliability/Life. It is anticipated that as a result of this series of actions at the part level (screening, analysis of design and manufacturing), and effective failure analysis, that significant improvement in reliability and life will be realized.

PROBLEM/SCREENING SUMMARY

Scope. This summation is an accumulation of knowledge and experience gained in dealing with capacitor failures and in avoiding those failures. It addresses itself to the causes and effects of failures, and shows the suggested screens that will allow identification of capacitors having latent or incipient defects.

This summary is aimed toward identifying capacitor problem areas and failure causes. Having identified problems, and recognizing that the typical user is concerned with eliminating this problem from a group of capacitors on-hand, suggestions are made for performing screening. These screening suggestions are based primarily upon industry experience. The problem areas have been grouped under the basic categories of open, short, parameter deviation, and mechanical anomaly.

ALERT Item No. Where directly applicable, the "ALERT Item No." of the ALERT report describing a specific cause for a failure is listed against that cause. Thereby a cross reference is provided between a specific failure cause found in the "ALERT Summaries" and the broader failure experience/avoidance knowledge shown in this presentation.

PROBLEM AREA/CAUSE AND SUGGESTED ACTION

CERAMIC CAPACITORS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
OPEN Lead separation Cold solder connection Inadequate lead bonding SHORT Solder reflow Contamination - solder between electrodes	 1 2 3 1 6	None. All these problems were caused by the internal use of low-melting-temperature solder. Upon application of external heat required to attach the capacitor to its circuit, the internal lead-attach solder melted to cause noted problems. Screening would not detect this type of problem since solder reflow temperatures would not be reached. Use heat sink.
OPEN Broken leads	 4	Precap Visual Examination prior to encapsulation
OPEN Cracked ceramic	 5	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
SHORT Cracked ceramic Breakdown of dielectric Shorted electrodes	 5 7 8	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
ELECTRICAL PARAMETER DEVIATION - HIGH TEMPERATURE COEFFICIENT Failed temperature coefficient test	9	Temperature Cycling; then measure Capacitance, Insulation Resistance (or DC Leakage), and Dissipation Factor at low temperature, high temperature, and at 25°C
ELECTRICAL PARAMETER DEVIATION - HIGH LEAKAGE AND CAPACITANCE OUT OF TOLERANCE Cracked ceramic	5	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)

CERAMIC CAPACITORS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
ELECTRICAL PARAMETER DEVIATION - LOW INSULATION RESISTANCE		Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
Deformed plates	10	
Breakdown of dielectric	11	
EXTERNAL MECHANICAL ANOMALY		Visual Examination
Damaged leads	12	
Cracked case	13	
EXTERNAL MECHANICAL ANOMALY		Measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage; followed by Visual Examination)
Improper marking	14	

SOLID TANTALUM CAPACITORS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
OPEN		Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
Termination metallization separation (slug to case)	15	
Lead separation	16	
SHORT		Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
Breakdown of dielectric	17	
Contamination - internal solder balls	18	
SHORT		Follow proper installation procedures including use of heat sink
Contamination - solder between tubelet and case	19	
ELECTRICAL PARAMETER DEVIATION - HIGH DC LEAKAGE		Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage); Radiographic Inspection and Delidding/Dissection
Wrong anodes	20	
ELECTRICAL PARAMETER DEVIATION - HIGH DC LEAKAGE		Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
Breakdown of dielectric	21	
ELECTRICAL PARAMETER DEVIATION - HIGH DISSIPATION FACTOR		Temperature Cycling; then measure Insulation Resistance, Capacitance, and Dissipation Factor; Dissection
Poor solder bonds	22	

WET-SLUG TANTALUM CAPACITORS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
ELECTRICAL PARAMETER DEVIATION - HIGH DC LEAKAGE Incorrect tantalum risers Electrolyte leakage Defective internal seal	 23 24 25	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
OPEN Lead separation	 26	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
ELECTRICAL PARAMETER DEVIATION - LOW CAPACITANCE Improper cathode preparation	 23	Temperature Cycling; then measure Insulation Resistance (or DC Leakage), Capacitance, and Dissipation Factor
EXTERNAL MECHANICAL ANOMALY Defective seal	 27, 28 29, 30	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)

GLASS CAPACITORS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
OPEN Lead not fused to plates	 31	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
ELECTRICAL PARAMETER DEVIATION - HIGH SERIES RESISTANCE Void between end cap and capacitive element	 32	Temperature Cycling; then measure Insulation Resistance (or DC Leakage), Capacitance, and Dissipation Factor
ELECTRICAL PARAMETER DEVIATION - LOW CAPACITANCE Decrease in dielectric constant	 33	Temperature Cycling, Burn-In, Seal Test; deage by exposing part to temperature above the Curie point with no voltage applied for one hour; then age for 100 hours at ambient temperature; then read Capacitance, Dissipation Factor, and Insulation Resistance

MISCELLANEOUS CAPACITORS

TYPE	PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION SCREEN (see "Screening Inspections and Tests")
AIR, VAR	OPEN Poor stator terminal solder connection	 34	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)

MISCELLANEOUS CAPACITORS

TYPE	PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION SCREEN (see "Screening Inspections and Tests")
AIR. VAR	SHORT Contamination - metal particles within capacitor Deformed plates	 35 36	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
AIR. VAR	UNADJUSTABLE Contamination - solder resin in moving parts	 34	Monitor Capacitance and Dissipation Factor vs rotation
ALUM. ELECT	OPEN Internal lead separation	 37, 38	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
ALUM. ELECT	EXTERNAL MECHANICAL ANOMALY - DEFECTIVE HERMETIC SEAL Incompatibility of materials	 39	Temperature Cycling, Seal Test (check for electrolyte leakage if applicable); then measure Insulation Resistance (or DC Leakage), Capacitance and Dissipation Factor; and Visual Examination
MET FILM	EXTERNAL MECHANICAL ANOMALY Improper marking	 40	Measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage); followed by Visual Examination
MET-MYLAR	OPEN Lead separation	 41	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
MET-PAPER	OPEN Internal lead broken	 42	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
MICA	ELECTRICAL PARAMETER DEVIATION - INSTABILITY Damaged lead-tin contact foil	 43	Temperature Cycling; then measure Insulation Resistance (or DC Leakage), Capacitance, and Dissipation Factor
MYLAR FOIL	OPEN Improper bonding, lead-to-foil	 44	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
PAPER	OPEN Improper bonding, lead-to-foil	 45	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
POLYSTYRENE	OPEN Improper lead attachment	 46	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)

MISCELLANEOUS CAPACITORS

TYPE	PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION SCREEN (see "Screening Inspections and Tests")
POLYSTYRENE	SHORT Breakdown of dielectric	47	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
TANTALUM FOIL	OPEN Lead separation	48	Temperature Cycling; then measure Insulation Resistance (or DC Leakage), Capacitance, and Dissipation Factor
TANTALUM FOIL	SHORT Electrolyte leakage	49	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
TANTALUM FOIL	ELECTRICAL PARAMETER DEVIATION - HIGH DC LEAKAGE Internal seal defective Contamination - metallic particles in mylar sleeving	 50 51	Temperature Cycling, Burn-In, Seal Test; then measure Capacitance, Dissipation Factor, and Insulation Resistance (or DC Leakage)
TANTALUM FOIL	ELECTRICAL PARAMETER DEVIATION - LOW CAPACITANCE Faulty anode lead-to-foil welds	52	Temperature Cycling; then measure Insulation Resistance (or DC Leakage), Capacitance, and Dissipation Factor

SCREENING INSPECTIONS AND TESTS

Basic Screening. The screening inspections and tests suggested for capacitors included in the Problem/Screening Summary are as follows:

1. Temperature Cycling
2. Burn-In; sometimes called "voltage conditioning," "voltage aging," or "voltage stabilization"
3. Seal Test (for hermetic devices)
4. Electrical Measurements
5. Visual Examination
6. Radiographic Inspection

Objective. The purpose of the screening is to allow detection of parts that: (1) have been improperly processed by the manufacturer, (2) contain flaws or weak spots in the dielectric (including voids and contamination), (3) have poor solder or weld connections, or (4) have any other anomalies that could result in a failure under normal operating conditions.

Additional Screening. In cases where specific characteristics are critical in the function of the using equipment, e.g., temperature coefficient and capacitance drift, such critical parameters should be added to the requirements of these screening tests.

Envelope Removal/Dissection. The basic approach taken here is to subject each of the devices to a test procedure in order to make a one-by-one acceptance determination. The disadvantage of this approach is the underlying assumption that the internal construction materials, processes, etc. from part-to-part are homogeneous so that the devices can be treated as a uniform lot. If the devices are not produced under similar design criteria and manufacturing controls which permit a heterogeneous lot to exist, a single screening procedure may not be the optimum for all units. For this reason, it is frequently desirable to examine the internal design and construction. This is accomplished, first, by a nondestructive radiographic inspection; and second, by performing a destructive envelope removal or dissection on a limited sample of devices. This procedure is more meaningful if a design/construction baseline has been established as a comparison criterion.

1. TEMPERATURE CYCLING — MIL-STD-202, METHOD 102 (5 cycles) (ref 2)

   General. This environmental exposure will assist in detecting a variety of design and manufacturing deficiencies resulting from materials with incompatible temperature coefficients of expansion, inadequately bonded materials, and materials with improper chemical composition.

   Complementary Tests. Seal test and electrical measurements will detect degradation and catastrophic failures resulting from the temperature cycling exposure. Capacitance Dissipation Factor (or Power Factor) and Insulation Resistance (or DC Leakage) are the suggested electrical measurements to be performed after Temperature Cycling and Seal Test. Test condition selected must be compatible with the part characteristic.

2. BURN-IN

   Burn-in typically consists of the application of rated voltage at maximum rated temperature for a period of time associated with the type of dielectric. The purpose is to stress the capacitor electrically and thermally to the maximum of its designed operating capability. Experience has indicated that this type of stress is extremely effective in detecting incipient failures. The number of hours that a part is burned in has evolved as a result of experience. This time is based on minimizing the infant mortality rate of a specific part type. A typical burn-in time is 100 hours.

3. SEAL TEST — MIL-STD-202, METHOD 112 (ref 2)

   General. The purpose of this test is to verify the integrity of the hermetic seal. Typical failure areas occur where materials are fused, brazed, or soldered to make the final seal. The seal test will detect manufacturing defects, damage resulting from handling, seal failures resulting from mismatched temperature coefficient of expansion of materials, etc.

Hermetic Seal. A hermetic seal serves basically two purposes: (1) to prevent moisture, cleaning fluids, or other contaminants from coming in contact with the capacitor elements, and (2) to prevent electrolyte from leaking out of wet-electrolytic type capacitors.

Metal/Glass Seal. Metal/glass hermetically sealed capacitors should be tested per MIL-STD-202, Method 112, Test Condition C (ref 2).

Transparent Glass Case. Transparent glass case fixed capacitors should be seal tested per MIL-C-23269 (ref 3) using Zyglo penetrant for 3 minutes under 20 psig. Dye that penetrates broken seals can later be detected by using ultraviolet light.

Opaque Glass Case. Opaque glass case fixed capacitors should be treated per MIL-C-23269 (ref 3), exposure at 5 psig in a steam atmosphere for 20 to 30 minutes, followed by IR measurement, to evaluate seal integrity.

Moulded/Dipped Epoxy Case. Moulded and dipped epoxy cased capacitors are not considered hermetically sealed, therefore, seal testing is not normally required.

Broken Seal Effects. Fluid from a wet-electrolytic capacitor may corrode other components or conductors in the vicinity of the leak even though the capacitor may continue to function within specification limits. In the nonwet type construction, a broken hermetic seal could result in low IR (or short) of the capacitor following moisture environment exposure. Therefore, the effect of a broken seal depends not only on the type of capacitor involved but also on the environmental conditions during operation.

4. ELECTRICAL MEASUREMENTS — MIL-STD-202, METHOD 302, 305, and 306 (ref 2)

General. Electrical Measurements (including Capacitance, Dissipation Factor or Power Factor, and Insulation Resistance or DC Leakage) are used to check the electrical characteristics, parametric drift resulting from exposure to the various environmental test conditions, and catastrophic failures.

When Performed. These tests need not be performed following each environmental exposure, but are suggested as final tests in the screening cycle. It also may be desirable to perform electrical measurements at the beginning of screening tests in order to immediately eliminate out-of-tolerance parts from the screening cycle.

5. VISUAL EXAMINATION

Following completion of screening tests, parts should be visually examined for identification and damage. Physical damage may have occurred as a result of handling during screening test or as a result of the environmental exposures.

6. RADIOGRAPHIC INSPECTION — MIL-STD-750, METHOD 2076 (ref 4)

Radiographic inspection is an effective screening test for solid tantalum capacitors. X-ray the capacitor in two planes at 90 degree rotation, perpendicular to the capacitor's longitudinal axis. Normally this test is performed in order to determine the positioning of the internal material and the existence of internal damage. Performing radiographic inspection for other types of capacitors may be beneficial.

7. ENVELOPE REMOVAL/DISSECTION

A sample from each lot (e.g., lot-date-code) has its envelope removed and/or is dissected in order to detect internal anomalies such as part damage, poor workmanship, improper materials, etc. It is suggested that a sample base line dissected part be used as a standard for comparison.

CERAMIC CAPACITORS

CHARACTERISTICS

Why Ceramic. As was discussed previously, a capacitor is formed by separating two conductive plates by an insulating dielectric. The value of capacitance obtained is directly related to the dielectric constant as well as to other physical factors. With the advent of the barium titanate ceramic, a material was made available having a dielectric constant as high as ten thousand in contrast to other capacitor dielectric materials such as paper, mylar, mica, etc. having dielectric constants up to 10. The reason for the existence of the ceramic capacitor is the fact that its high dielectric constant allows the attainment of the highest capacitance to volume ratio of all nonpolar capacitors in commercial production.

Properties of Ceramic. Many of the properties associated with ceramic capacitors are associated with the fact that their dielectric material is crystalline in nature and obeys the physical laws associated with crystals. Two factors that particularly concern us are the effects of the Curie point and voltage stress.

Temperature Effects. At approximately 120°C, barium titanate crystals experience a drastic change in form, resulting in large variations in capacitor characteristics. The crystalline structure changes at this point from tetragonal (elongated cube) to cube. At this temperature, known as the Curie point, the dielectric constant experiences an increase on the order of 5 to 10 times, resulting in increased capacitance. It is this, and other temperature effects (e.g., decreased insulation resistance and decreased dissipation factor with increase in temperature), that induces manufacturers to combine barium titanate with other proprietary additives (e.g., compounds of calcium, tin, strontium, etc.) to produce temperature-stable capacitors.

Voltage Effects. Another shortcoming of ceramic capacitors is the effect of voltage stress on the crystalline structure. Exposure to full rated voltage can cause a capacitance decrease on the order of 5 percent. Capacitors designed for extremely small size (e.g., highest dielectric constant and thinnest ceramic plate) tend to be more sensitive to voltage stress. Capacitance decrease caused by voltage stress is relieved after several hours of shelf aging at ambient conditions. It should be noted that one of the significant advantages of a ceramic capacitor is its nonpolar characteristic. Ceramic bodies are available which are capable of withstanding dc voltage of either polarity, and in combination with ac.

Frequency Effects. It should be recognized that a capacitor, in addition to providing capacitance, also provides series and shunt inductance and resistance. As the resonant frequency of the combination of inductance and capacitance found in a specific capacitor is approached, it will begin to appear as though it were a resistor. This frequency effect can be shifted to the higher portion of the spectrum by control of design and installation techniques.

Specification Parameters. The above discussion has served to define application limitations of ceramic capacitors related to physical characteristics associated with the ceramic body and with construction techniques used in the manufacture of the devices. These limitations can be described as specification limits for use by manufacturers and using designers. Deviations from these limits can lead to equipment failure. The next section will describe problems and failure mechanisms found in capacitors caused by design deficiency, lack of process control, and inadequate quality control.

CERAMIC CAPACITORS

DESIGN AND PRODUCTION CONSIDERATIONS

Failures Related to Process. A typical ceramic capacitor (Figure 3-1) and a typical assembly flow (Figure 3-2) are presented together with the suggested controls required to assure a reliable product. The "Critical Process" is defined for each of the manufacturing steps. Relationship is established between failure causes and the manufacturing process. Having experienced a specific problem, one could identify those manufacturing steps with potential for contributing to the failure.

Assembly Flow. The manufacturing flow of a ceramic capacitor is essentially the same for all manufacturers, differing principally in the degree of process controls, number of production tests, and extent of automation. The assembly flow as described is typical of what may be expected for capacitors of the type produced to meet MIL-C-39014 (ref 5) specifications. Significant variables are listed on the typical flow diagram with those operations that are considered critical for the design of a reliable capacitor. In-process inspection and testing may vary from one manufacturer to another depending on the sizes of the lots produced and the degree of automation.

TYPICAL CERAMIC CAPACITOR DESIGN (Figure 3-1)

ITEM	ITEM NAME	MATERIAL OF CONSTRUCTION
1	Leads	Gold-plated nickel wire — MIL-STD-1276, Type N2 (ref 6)
2	Encapsulant	Transfer moldable rigid plastic such as epoxy or diallyl phthalate
3	Conductor Plates	Platinum alloy (modified with Pl, Au, and Ag)
4	Dry Ceramic	Barium titanate (modified with Sn, Ca, Mn, Pb oxides)
5	End Silver	Silver silicate mixture with B, Na, Al, and K as trace oxides
6	Internal Solder	Hi-temp solder (Ag 1.5 or equivalent)

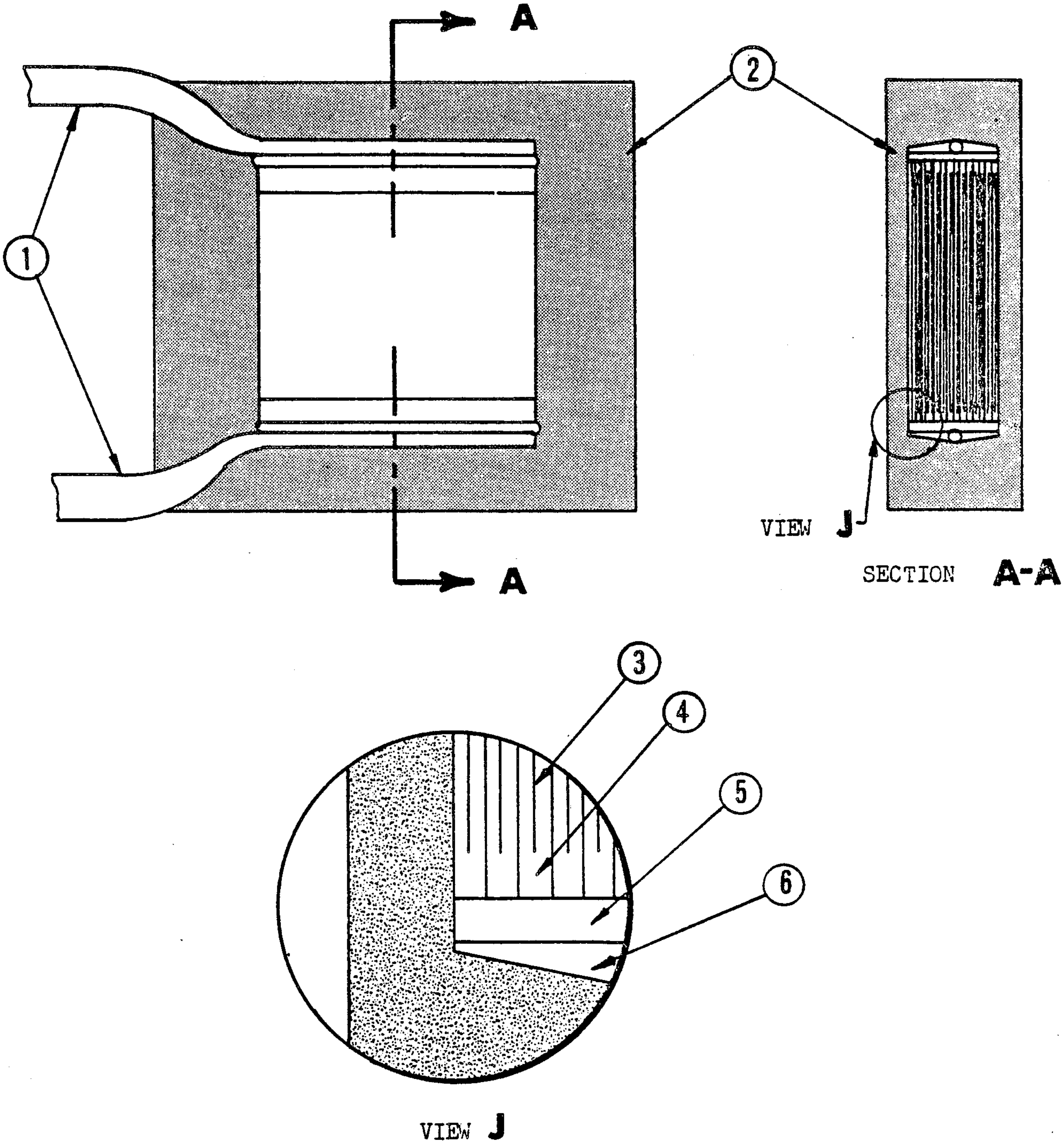

Figure 3-1. Typical Ceramic Capacitor

ASSEMBLY FLOW

General. With reference to the assembly flow diagram (Figure 3-2), the first four operations are considered as proprietary and some manufacturers will not divulge any information concerning the powder mixing, additives, and viscosity of the ceramic slurry. An examination of the implementation of the in-process inspection requirements and process control documents gives an indication of the consistency of quality being built into the parts but not necessarily an indication of good quality.

Slurry. Improper viscosity of the slurry can result in nonuniform thickness of plates and in lower dielectric strength of the finished capacitor. An out-of-tolerance condition of electrical characteristics can result from incorrect additives. Poor registration of stacked laminates results in a wider distribution of capacitance values.

Curing. Firing of the slug (curing) is one of the most critical processes in the production of a reliable capacitor. All volatiles must be driven out of the green chip in order for the laminates to fuse, thus creating a monolithic unit.

Improper Curing. Improper curing occurs when the external surface of the ceramic solidifies (becomes nonporous) before internal gases can escape. This can be caused by poor curing temperature control, excessive volatile material, etc. Gases trapped within the slug can create voids, deformations, cracks, and even shifting of plates. These types of discrepancies may not cause failure immediately but result in low quality parts. High temperature insulation resistance measurement may be used to detect gross discrepancies in the finished capacitors. A visual examination of dissected specimens will reveal discrepancies that are not detectable by electrical measurements. When improper curing is established as the cause of failure of a part, the entire lot of parts become suspect and should be scrapped.

Insuring Reliability. It is because of the above considerations that special part requirements become necessary where these devices are used in long-life and critical applications. They include: (1) lot rejection because of excessive screening fallout, (2) failure analysis by the vendor of catastrophic screening failures, and (3) user receiving inspection and envelope removal.

Assembly Precautions. Termination end silvering, tinning, and attachment of leads require proper cleaning procedures and good soldering techniques to prevent open or intermittent type failures. Precautions must be taken to avoid thermal shock during silver firing. Preheating of the slug may be required during tinning and during lead attachment. These precautions are evident in the process control procedures of a manufacturer that produces high-reliability parts.

FLOW DIAGRAM			RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL	MANUFACTURING OPERATION	CRITICAL PROCESS	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
Dry Ceramic (4)	Mix and mill	Particle size, purity of powder and calcining temperature, and amount of additives and homogeneity			A2; B2, 5; D1	
Solvents Resins Plastic	Ceramic slurry	Viscosity of slurry and freedom from conductives				
	Slip cast dry and roll green stock	Thin spots and cleanliness from contamination		B, C, D	A3, 6; B2, 4, 5; D1	
	Cut to size for electroding					
Conductor Plates (electrode ink) (3)	Silk screen ink on green ceramic sheets and air cure	Uniformity of electrodes and cleanliness	B		C3	
	Stack laminates and cut into capacitor chips	Uniformity of cut and sharpness of cutter			A7; B5, 6	
	Set load and air dry					
	Fire	Programming of temperature rise, degree, and reduction time			A2, 5, 6; B1, 4, 5; C2. 3; D1	
	Tumble to expose electrodes	Exposure of all plates	D		A1, 4; C1	
End Silver (paste form) (5)	Silver ends of chips for lead attach	Uniformity of end coverage	A, C		A1, 4; C1	
	Fire silvered end chips	Fusing of silver and ceramic temperature change rate	A, C		A1, 4; C1	
	Electrical Measurements					
Solder (6)	Tin and clean chips	Good solder wetting, and elimination of conductive and corrosive contaminants	A, C	A	A1; B3; C1, 2	
Leads (1)	Attach pretinned leads to chips	Solder time and temperature	A, C	A	A1; B2; C1	A, C
Inner Encapsulant	Undercoat and cure	Curing of encapsulant				
Other Encapsulant (2)	Assembly in holder and pot or mould assy	Centering chip in case				A, E, C, E, F
	Electrically test					
	Mark					
	Screening tests					
	Package and ship					

NOTE: For items (1) through (6) see Figure 3-1.

Figure 3-2. Ceramic Capacitor - Typical Assembly Flow with Related Problem Codes

CERAMIC CAPACITORS

FAILURE ANALYSIS TECHNIQUES

General. Failure analysis is a corrective action-related procedure. Only after knowing why a part failed can action be taken to minimize future failures. Failure analysis findings can show the need for redesign (improvement in materials, processes, and controls) or proper part application.

Predominant Failures. Failures of ceramic capacitors most frequently result from problems associated with lead attachment or defective ceramic plates.

Encapsulant Removal. The removal of encapsulating material surrounding the plate structure frequently makes failure analysis difficult. The depotting (dissolving) operation if not properly conducted, can result in extreme swelling and introduce such massive damage that the positive identification of the cause of failure is not possible.

Dissection Precautions. Grinding and polishing, if not performed in small increments, can easily pass through the failed area without detecting its presence.

Failure Analysis Flow. The failure analysis flow diagram, (Figure 3-3) which follows, provides for maximum nondestructive evaluation of the failed part prior to the dissecting or depotting operation.

Relationship to Failures. Where it is relevant, each step of the failure analysis procedure (Figure 3-3) is related to one of the four major problem areas and their causes by a coding system which is defined on the foldout in the Appendix. Thus, one experiencing a specific type of failure can identify those steps in the failure analysis most likely to reveal the problem.

TEST/EXAMINATION	PROCEDURE	RELATED PROBLEM CODES (see foldout in the Appendix)			
	WHEN FAILURE IS / LOOK FOR	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
NONDESTRUCTIVE MECHANICAL					
External Visual Examination	Note all identifying markings and external damage	A	B		A, B, C, D
Radiographic Inspection	If fixed focus X-ray used, photograph in two planes mutually perpendicular to the longitudinal axis. If Vidicon (imaging) used, examine and photograph anomalies as observed	A, C, D	A, C, D	A1, 3, 4, 5, 6, 7; B5, 6; C2, 3	
PROBLEM AREA VERIFICATION					
NONDESTRUCTIVE ELECTRICAL					
Electrical Measurements	Measure and record capacitance, dissipation factor (DF), dc leakage (DCL) and insulation resistance (IR) (at high and low temperature if necessary)				
INDUCING FAILURES					
Special Conditioning	Baking, temperature cycling, or vibration only if required to confirm problem area				
Electrical Measurements	Capacitance, DF, DCL, or IR as required				
PROBLEM CAUSE VERIFICATION					
Depotting and Examination	Decapsulant may cause severe swelling of plastic such as to mark the failure. Proper depotting procedure must be developed on other than the failed part	A, C	A, B, D	A1, 5, 6, 7; B1, 2, 3, 4, 5, 6; C1, 2	
Dissection and Examination	May be performed after depotting. Depotting may be eliminated if adequate depotting procedure is not available. Must be performed in small increments so as not to grind through the failed zone	A, B, C, D	A, B, C, D	A all; B all; C all	
Materials Analysis Spectrographic Microprobe	May be performed in conjunction with depotting or dissection. Analyze all foreign material not otherwise identifiable		A, B	A2; B2, 3	A

Figure 3-3. Ceramic Capacitor - Typical Failure Analysis Flow with Related Problem Codes

SINTERED ANODE TANTALUM CAPACITORS

CHARACTERISTICS

Design Considerations. Sintered anode tantalum capacitors, which include both wet-slug and solid types, are primarily used where a relative high value of capacitance is required in a limited space, the disadvantage of polarity presents no problem, and relatively low voltage circuits are used.

From previous discussions, it can readily be seen that total capacitance is a direct function of available surface area. The sintering process produces an amorphous solid with a virtually infinite surface when compared to the useful dielectric surface planes of the previously described lamellate bodied ceramic capacitor. Improvements in volumetric efficiency, when compared to the nonpolar ceramic, approach 35 times as great for the solid type and 73 times for the wet-slug type.

Disadvantages of these devices include temperature/current limitations for both types, plus electrolyte containment for the wet-slug variety.

Both types are self-healing because of the different processes described below, the liquid type proving to be more effective in this characteristic.

Solid Tantalum Capacitor Dielectric Film Considerations. The so-called solid tantalum capacitor consists primarily of a sintered tantalum anode with three successive coatings: manganese dioxide (MnO_2), collodial carbon, and silver. The sintered anode slug is anodized to produce a film of tantalum pentoxide (Ta_2O_5) before formation of the MnO_2 coating. The MnO_2 coating is formed by pyrolytic conversion of the manganous nitrate that has penetrated all pores of the anode while the slug was immersed in a manganous nitrate bath. Leakage current conduction is ionic across the Ta_2O_5/MnO_2 semiconductor interface. The principal cause of excessive leakage is presence of impurities at or adjacent to this interface.

Fortunately, the leakage current caused by this dielectric imperfection is not a stable value. The saving factor is the reaction of the MnO_2 material when conducting current away from the leak fault area. This material, when subjected to high current densities, becomes hot and reduces to a lower oxide (Mn_2O_3) which has a resistivity of approximately ten thousand times that of MnO_2 and causes the Ta_2O_5 to reform. These changes reduce the fault current to a low level and are a self-healing process. Unfortunately, this self-healing effect is only beneficial where the short circuit area is small. If the area is large, the heat will destroy larger areas of dielectric and result in an avalanche condition that will destroy the device.

From the above, the synergistic relation between temperature and current density becomes apparent, and compensation for this phenomenon requires derating of electrical capabilities when the part is used at higher temperature ranges.

Wet-Slug Tantalum Capacitor Dielectric Film Consideration. The wet-slug tantalum capacitor consists of a sintered tantalum anode that is immersed in a gelled or liquid electrolyte and contained by a silver can with a platinized inner surface. Again, the sintered anode is anodized to produce a Ta_2O_5 dielectric film. The gelled electrolyte is either sulphuric acid or lithium chloride and acts as a conductor between the anode slug and the cathode (can). From this discussion, it can be seen that the current transfer is an anodic process. Furthermore, localized leakage, as would be associated with minor impurities at or near the surface, is self-healed by a local reanodizing. Unfortunately, the leakage and healing processes have a thermal by-product, and again, the synergistic combination of temperature and current density must be guarded against by appropriate derating.

Another problem associated with the surface of the wet-slug type is the deposit of silver on the dielectric film. The silver is leached from the can surface by the sulfuric acid content of the electrolyte. This material interferes with self-healing and is also associated with drift in value with aging.

Wet-Slug Electrolyte Transfer. Proper containment of the corrosive and conductive electrolyte used in the wet-slug presents another problem with use of these devices.

In order for the device to retain integrity as a capacitor, electrical insulation must be maintained between the internal tantalum slug metal and the electrolyte. This problem becomes most severe in insulating the anode egress lead. Typical wet-slug designs, until recently, included an eyelet-to-glass end seal. In order to provide hermeticity, a nickel wire (welded to a tantalum riser emanating from the slug to provide an electrical connection) was soldered in the eyelet as the final seal operation. It becomes essential to electrically insulate the nickel and eyelet from the electrolyte.

Because of its conductive nature, the electrolyte must be kept from spreading to the inner surface of the glass-to-metal hermetic seal. For it can, upon spreading across the glass, act as a conductive bridge and produce a shorting condition. The electrolyte is normally contained in its prescribed area by an elastomeric seal. With improper fit, such as grooving of the anode stem and/or displacement by oscillation of the slug under forces caused by vibration, transportation of the electrolyte into the end seal area becomes relatively easy.

Recently, sealing techniques have been developed allowing the tantalum riser to seal directly to the glass, which eliminates many of these problems.

Not to be overlooked is the relatively high rate of expansion of the electrolyte with rise in temperature. The hydraulic pressure generated by this mechanism has been known to disrupt the soldered portions of the seal and result in spewing of the corrosive material onto adjacent components.

Specification Parameters. The foregoing discussion has been presented as a guide to define the application limits of sintered anode tantalum capacitors, as well as the associated inherent physical characteristics and construction techniques used in the manufacture of these devices. These limitations can be described as specification limits for use by manufacturers and design engineers. Deviations from these limits can lead to equipment failures. The next subsection will describe problems and failure mechanisms found in capacitors caused by design deficiency, lack of process control, and inadequate quality control.

SINTERED ANODE TANTALUM CAPACITORS
DESIGN AND PRODUCTION CONSIDERATIONS

General. Typical sintered anode tantalum capacitors are shown in Figure 3-4 (solid tantalum) and Figure 3-5 (wet-slug tantalum). Figures 3-6 and 3-7 describe the typical assembly flow of these capacitors.

TYPICAL SOLID TANTALUM CAPACITOR DESIGN (Figure 3-4)

ITEM	ITEM NAME	MATERIAL OF CONSTRUCTION
1	Cathode Lead	Nickel
2	Can	Solder plated brass
3	Solder	Hi-temp solder
4	Silver Coat	Silver suspension in binder with volatile solvent
5	Carbon Coat	Collodial carbon
6	Anode Stem	Capacitor-grade tantalum wire
7, 13, 14	Header Assembly	Procured glass-metal (hermetic type seal)
8	Anode Stem to Anode Lead Lap Weld	
9	Oxidizer Surface	Manganese dioxide
10	Dielectric Film	Tantalum pentoxide
11	Tantalum Anode	Sintered tantalum
12	Solder Seal	60/40 solder
15	Eyelet Seal	SB-5 solder
16	Anode Lead	Nickel

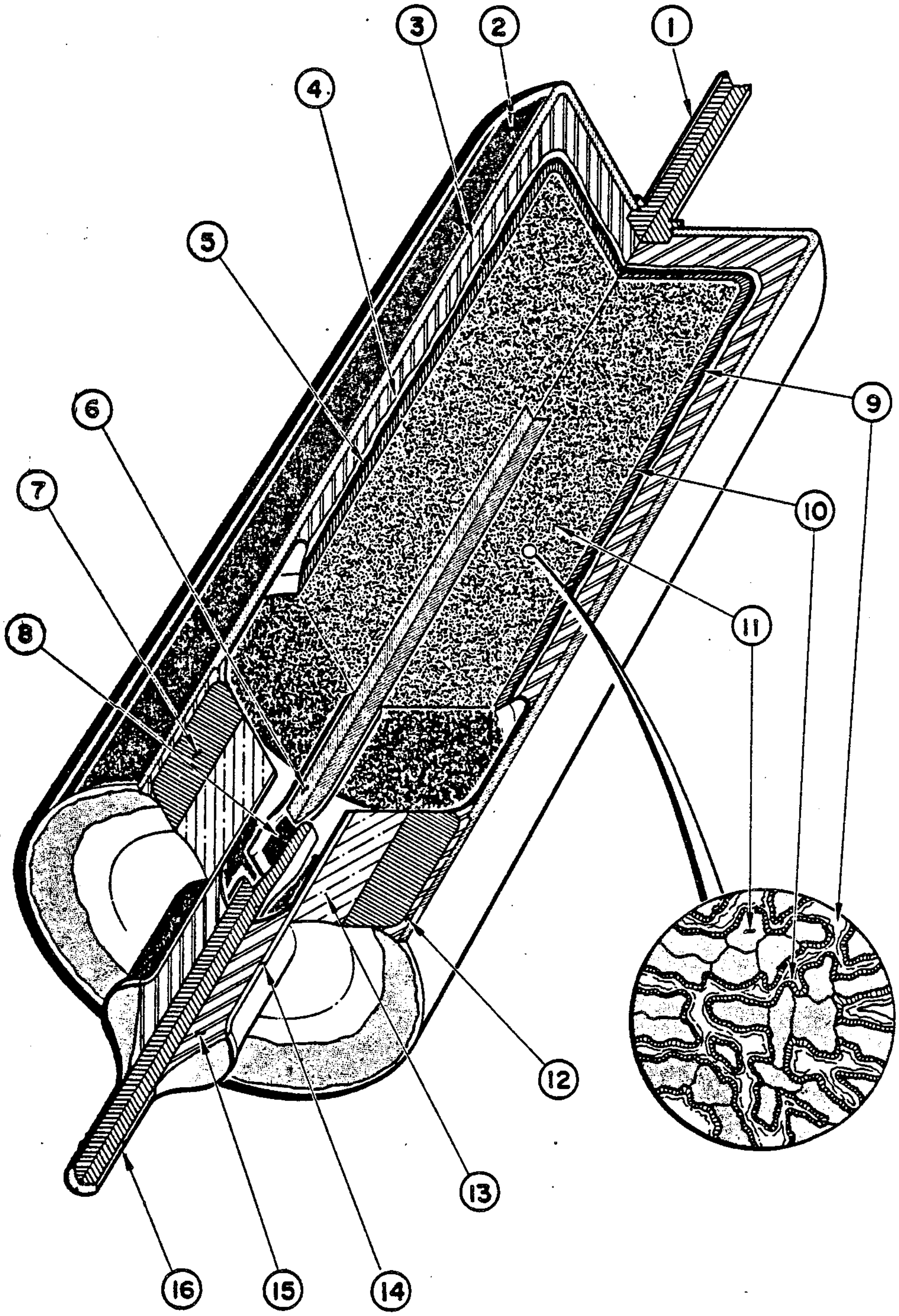

Figure 3-4. Typical Solid Tantalum Capacitor

TYPICAL WET-SLUG TANTALUM CAPACITOR DESIGN (Figure 3-5)

ITEM	ITEM NAME	MATERIAL OF CONSTRUCTION
1	Weld	Cathode lead to case
2	Platinization	Platinum black inner case coating
3	Bottom Cup	Acid resistant elastomer
4	Anode Slug	Sintered tantalum
5	Dielectric	Tantalum pentoxide
6	Electrolyte	Gelled sulphuric acid
7	Anode	Basic tantalum
8	Case	Fine silver
9	Compression Ring	Glass-sealing metal
10, 12	Solder	Hi-temp solder
11	Header Glass	Compression glass
13	Anode Lead	Nickel
14	Spacer Gasket	Acid resistant elastomer (internal seal)
15	Anode Riser	Capacitor-grade tantalum wire
16	Header Eyelet	Glass-sealing metal

Note: 9, 11, and 16 comprise the header assembly

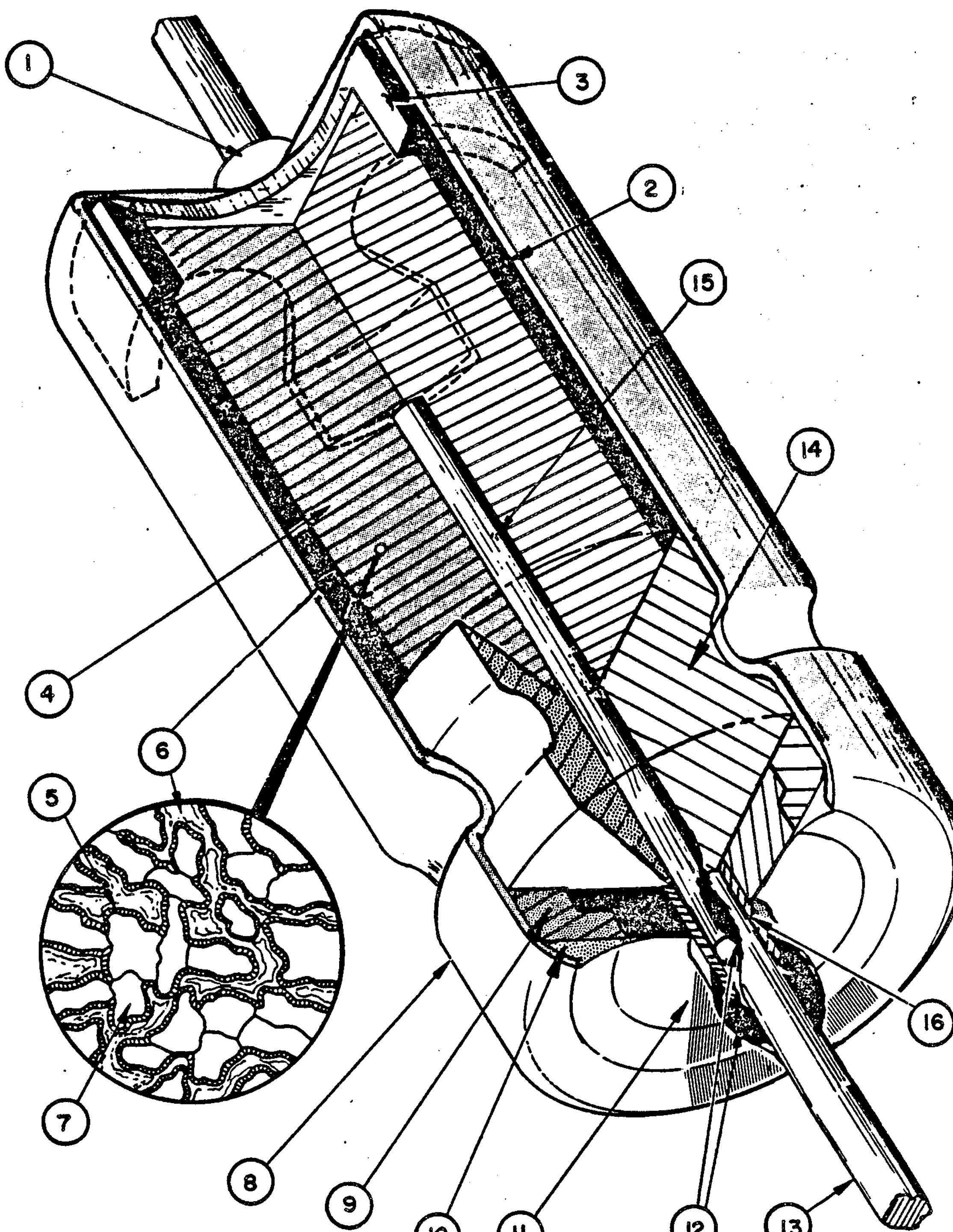

Figure 3-5. Typical Wet-Slug Tantalum Capacitor

ASSEMBLY FLOW

General. With reference to the assembly flow diagrams (Figures 3-6 and 3-7), the processing, formation, and coating of the anode slug is considered proprietary by most manufacturers. Some manufacturers will divulge no information with regard to particle size of tantalum powders, additives, resins, and solvents used in preparation of the sintered tantalum anode, nor can definitive information be obtained on basic composition or processing parameters for anode coating(s). A review of in-process control gives an indication of consistency of quality being built into parts, but the user is dependent on screening, including life test, to establish tentative quality standards.

Anode Preparation. One of the most critical operations is anode preparation. Each of the sequential steps requires rigorous control. First, the mixing and milling of the basic tantalum powders can result in undesirable variations in particle size. The blending of the required additives, storage, and transfer of the powder mixture prior to pressing can result in the introduction of contaminants. Second, pressing can result in extremely porous structures and/or poor adherence to the riser if insufficient pressure is applied, and third, the final sintering, without control of chamber atmosphere and/or insufficient time and temperature, can result in failure to remove all organics and volatiles and/or deposit of gaseous contaminants. All of these can result in a nonhomogenous structure that can include localized clumping and nonuniform distribution of the tantalum particles.

This nonhomogeneous structure leads to nonuniform current densities which precipitates dielectric rupture at relative low overstress transient, i.e., scintillations. The surface of a nonhomogeneous anode, furthermore, is not ideal for application of uniform coatings of the other materials that are required to complete the capacitor.

Fits and Sizing of Wet-Slug Types. Inadequate fits of supporting members (e.g., bottom clip, depth of crimp, etc.) and sizing of anode with respect to finished can dimensions can result in devices that are extremely sensitive to damage by mechanical vibration. In addition to vibration testing during screening, randomly selected samples should be dissected and physically measured for conformation of proper fit.

Insuring Reliability. It is because of the above considerations that special part requirements become necessary where these devices are used in long-life and critical applications. They include: (1) lot rejection because of excessive screening fallout, (2) failure analysis by the vendor of catastrophic screening failures, and (3) user receiving inspection and envelope removal.

Assembly Precautions. As the most critical processes are preparation and coating(s) of anode, extreme care should be taken with respect to adherence to established process controls for these procedures. Compliance can best be monitored by the in-process electrical test prior to assembly into case.

FLOW DIAGRAM					RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL		MANUFACTURING OPERATION		CRITICAL PROCESS	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
Tantalum Powder Solvents Plastics	11	Mill and mix		Homogeneity, purity, and size of particles		E	A8; C4	
Tantalum Wire Tantalum Powder Plasticizer	6	Press powder, wire and binder into slug		Dimension and density control	A		A8; C4	
		Sinter Ta slug		Control of atmosphere and thermal profile		E	A8; C4	
Electrolysis Solution	10	Form dielectric oxide	SLUG ASSEMBLY	Control of current, solution, temperature, and time		E	A2, 8; C4	
Manganous Nitrate Solution	9	Thermal reduction to MnO_2		Control of current, solution, temperature, and time		D	D1	
Collodial Carbon Solution	5	Carbon coat		Coverage control	E	D		
Silver Paint	4	Silver coat		Coverage control	E			
External Lead	16	Cut and weld to riser		Welding parameters	A			A, E
		Electrical test						
Can Assembly Solder Preforms Anode Assembly Header Assembly	1, 2, 3, 12, 6, 11, 16, 7, 13, 14	Assemble, place in fixture, and solder		Soldering time and temperature	E	A	B2; C2	F, H
Eyelet Solder Preform	15	Final solder seal (remove from fixture)		Soldering time and temperature		F		H
		Test						
		Label						
		Final inspection						
		Pack and ship						E, F, H

NOTE: For items (1) through (16) see Figure 3-4.

Figure 3-6. Solid Tantalum Capacitor - Typical Assembly Flow with Related Problem Codes

FLOW DIAGRAM				RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL	MANUFACTURING OPERATION		CRITICAL PROCESS	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
Case Cathode Lead (1) (8)	Clean and weld		Weld parameters	A			
	Mask and etch case		Mask location	E			
Platinic Acid (2)	Platinize (inside case)			E			
	Mask removal						
Tantalum Powder Organic Binder (7)	Mix ingredients	SLUG ASSEMBLY	Homogeneity, purity and particle size			A4, 8; C4	
Resin Anode Stub (15)	Press into slug		Control of size and density	A		A4, 8; C2, 4	
	Sinter Ta slug		Control of thermal profile, time, and atmosphere	A		A4, 8; C2, 4	
Electrolysis Solution (5)	Form dielectric oxide		Electrolyte composition, time, and applied current		A, D	A2, 3, 8; B2, 5	
External Lead (13)	Cut and weld lead		Welding parameters	A		C2	
	Electrical Test						
Spacer Gasket (14)	Add gasket and trim lead						
Bottom Cup (3)	Fit over anode		Selection of fit				
Slug Assembly, Cup, and Gasket	Assemble into case						
Electrolyte (6)	Dispense electrolyte		Volumetric control				
Header (9) (11) (16)	Solder seal		Soldering time and temperature	E	H	A4	
	Roll crimp		Depth and pressure		F		H
	Test				A, G	B2	B, F, H
	Mark and sleeve						
	Final inspection						
	Pack and ship						

NOTE: For items (1) through (16) see Figure 3-5.

Figure 3-7. Wet-Slug Tantalum Capacitor - Typical Assembly Flow with Related Problem Codes

SINTERED ANODE TANTALUM CAPACITORS

FAILURE ANALYSIS TECHNIQUES

General. Failure analysis is performed to establish remedies for the cause of part failure. It is used to define changes (where required) in component application criteria and/or installation and testing procedures. Very often it reveals subtle modifications of materials and processes used in part manufacturing and/or screening that can enhance application capability of the part.

Predominant Failures of Solid Tantalum. Failures of solid tantalum capacitors most frequently arise from rupture of the dielectric because of overstresses.

Predominant Failures of Wet-Slug Tantalum. The most common failure problem for wet-slug tantalum capacitors is short (including high dc leakage). This type of failure is associated with the rupture of the dielectric film caused by overstress and/or conductive bridging (displacement of the electrolyte). The displacement of the electrolyte is caused by mechanical overstress (vibration) or thermal overstress, leading to electrolyte seepage around the gasket. Physical leakage of electrolyte sometimes causes corrosion damage to other equipment.

Precautions. The predominant cause of abortive failure analysis is improper decanning with resulting loss of traces of shorting paths on can interior, on inner surface of seal, or on anode slug. Also, it may cause fracture of the internal lead, disruption of anode slug coating, and relocation of deposits on inner surface of the seal. If care is not exercised in removing the anode coatings, when analyzing a solid tantalum capacitor failure, meaningful film rupture and discoloration will be destroyed before being analyzed or recorded. All of these factors can lead to erroneous assumptions as to the cause of the failure.

Failure Analysis Flow. Failure analysis procedures for solid or wet-slug tantalum capacitors are very similar. Therefore, Figure 3-8 describes the failure analysis flow for both types of capacitors. Differences in procedures are indicated on the chart. The chart provides for maximum nondestructive evaluation of the failed part prior to the dissection or depotting operation.

Relationship to Failures. Where it is relevant, each step of the failure analysis procedure (Figure 3-8) is related to one of the four major problem areas and their causes by a coding system which is defined on the foldout in the Appendix. Thus, one experiencing a specific type of failure can identify those steps in the failure analysis most likely to reveal the problem.

TEST/EXAMINATION	PROCEDURE	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
		WHEN FAILURE IS / LOOK FOR		RELATED PROBLEM CODES (see foldout in the Appendix)	
NONDESTRUCTIVE MECHANICAL					
External Visual Examination	Note all identifying markings and external damage (photographs preferred).		F		A, B, E, F, G, H
Radiographic Inspection	If fixed focus X-ray used, photograph in two planes mutually perpendicular to the longitudinal axis. If imaging used, photograph observed anomalies.	A	A, C	A1, 4; B2; C1, 2, 4	
Hermeticity Test	Perform fine and gross leak test in non-conductive media. (MIL-STD-202, Method 112, Cond. C)		F	B2	H
PROBLEM AREA VERIFICATION					
NONDESTRUCTIVE ELECTRICAL					
Electrical Measurements	Measure and record capacitance, dissipation factor, dc leakage, and insulation resistance (at high, room, and low temperature as required)	A	A, B, D	A1; B2, 3, 5; C1, 2	
INDUCING FAILURES					
Special Conditioning	Baking, temperature cycling and/or vibration as required to confirm failure (monitored)	-	B, G,H		
Electrical Measurements	As required, repeat electrical measurement made under static and/or dynamic environmental conditions to detect induced changes in electrical parameters	A	A, D	A1; B2, 3, 5; C1, 2	
PROBLEM CAUSE VERIFICATION					
Decanning and Examination	Remove can. Examine inner surfaces of can and seal assembly plus outer surface of anode slug. Record (color photos preferred) all observed anomalies. Proper delidding procedure must be developed on other than the failed part.	A, E	A,D, E	A2, 3; B2, 5; C1, 2	
Solid Ta Only Anode Coating Examination	Selectively remove silver, carbon, and manganese-dioxide anode coatings in three independent, successive operations. Observe and record (color photos preferred) anomalies on surfaces.		D, E	A2, 3, 8; B5; C1, 2, 4	
Anode Examination	If anomalies are observed on stripped anode, photograph (S. E. M. technique) and analyze (microprobe). Dissection and examination at point of anomaly can determine its depth.		D, E	A2, 3, 8; B5; C4	

Figure 3-8. Solid and Wet-Slug Tantalum Capacitors - Typical Failure Analysis Flow with Related Problem Codes

GLASS CAPACITORS

CHARACTERISTICS

History. Glass capacitors were developed primarily for the purpose of providing a replacement part for mica capacitors. Since mica is imported, the concern that the source might not be available during time of war led to the design of a capacitor using glass as a dielectric in lieu of mica. In 1951 a Signal Corps specification, MIL-C-11272 (ref 7), was released as the first MIL-Spec concerning fixed, glass dielectric capacitors. In 1963 a Navy specification, MIL-C-23269 (ref 3), was released as the first established reliability specification for fixed, glass dielectric capacitors. Both specifications are still active, however, parts designated as CYXX procured to MIL-C-11272 are no longer standard items for use in design except as replacement parts.

Design Considerations. Glass capacitors may be used in applications requiring capacitance stability in the most severe space environments, including radiation. The glass capacitor is less sensitive to nuclear radiation than any other type of capacitor. Glass capacitors are available in capacitance values ranging from 0.5 pF through 10,000 pF, in tolerances as tight as ±1 percent, and voltage ratings of 300 volts and up. They exhibit excellent capacitance retrace capability over a wide temperature range, show essentially zero dielectric absorption, and have a high degree of capacitance stability at frequencies up to one megahertz.

These capacitors are used in radio and radar transmitters for by-pass and coupling in UHF and VHF applications. They have been used in antenna coupling, high voltage power supplies, high voltage oscillators, resonant filters, and delay lines.

Porcelain, quartz, and other formulations of glass are used as dielectrics in the design of variable capacitors. Each dielectric possesses individual characteristics and limits the range of capacitance that can be provided for any particular design configuration. The glass used in fixed capacitors consists of two types, i.e., porcelain and glass ribbon. Porcelain capacitors have a capacitance temperature coefficient of 105 ± 25 ppm/°C, (also available in 0 ± 25 ppm/°C), as compared to 125 ± 40 ppm/°C exhibited by capacitors constructed with the glass ribbon.

The glass has a slightly better volumetric efficiency but the difference is not sufficient to make this a major design consideration. Both procelain and glass ribbon types are comparable to mica in volumetric efficiency at capacitance values of approximately 5,000 pF.

Reliability. Glass capacitors have been used with good success throughout the aerospace industry. Temperature, moisture, shock, and vibration within the limits of space environmental specifications have essentially no effect on the performance characteristics of this type of capacitor. The primary failure mode is a short occurring between the plates caused by breakdown of dielectric. Failures of these capacitors are a rare occurrence and those that have failed usually did so at a high voltage and high temperature. The cause can usually be traced to the existence of air bubbles in the glass ribbon from which the dielectric was made. Voltage conditioning at 3 to 5 times rated dc voltage is part of the MIL-C-23269 (ref 3), Group A inspection, and is performed on 100 percent of all parts supplied as failure rate "M" or better. The high voltage used to burn in these parts is probably the reason one seldom sees any failures of this type of capacitor. Failure rate "M" (1.0 percent/1,000 hours) is the best failure rate presently listed in QPL 23269 (ref 8). This should not be construed as an indication of the reliability limit of glass capacitors. The demand for this type of capacitor procured to the military ER specification has apparently been of insufficient quantity to economically justify the additional testing required for qualification to lower failure rates. The manufacturers have no present plans to obtain qualification to any higher reliability level.

Reliability of the glass capacitor is partly due to its simplicity in construction which consists of three basic materials. The conductive element of aluminum foil, (or silver in the case of the porcelain type), the glass dielectric which is the same as the case, and the lead wire. These materials when properly processed and assembled form one of the most reliable capacitors available today.

GLASS CAPACITORS

DESIGN AND PRODUCTION CONSIDERATIONS

Assembly Flow. The assembly flow as shown in Figure 3-10 is typical for fixed capacitors of glass ribbon type construction, and does not encompass all glass capacitors. Some manufacturers necessarily perform more material processing steps, some of which are proprietary. The flow diagrams for some glass capacitors closely approximates that shown for ceramic capacitors.

TYPICAL GLASS CAPACITOR DESIGN (Figure 3-9)

ITEM	ITEM NAME	MATERIAL OF CONSTRUCTION
1	Lead	Modified Dumet, gold plated
2	Dielectric	Glass ribbon
3	Conductor	High purity aluminum foil
4	Cover Glass	Same as dielectric
5	Foil to Lead Weld	

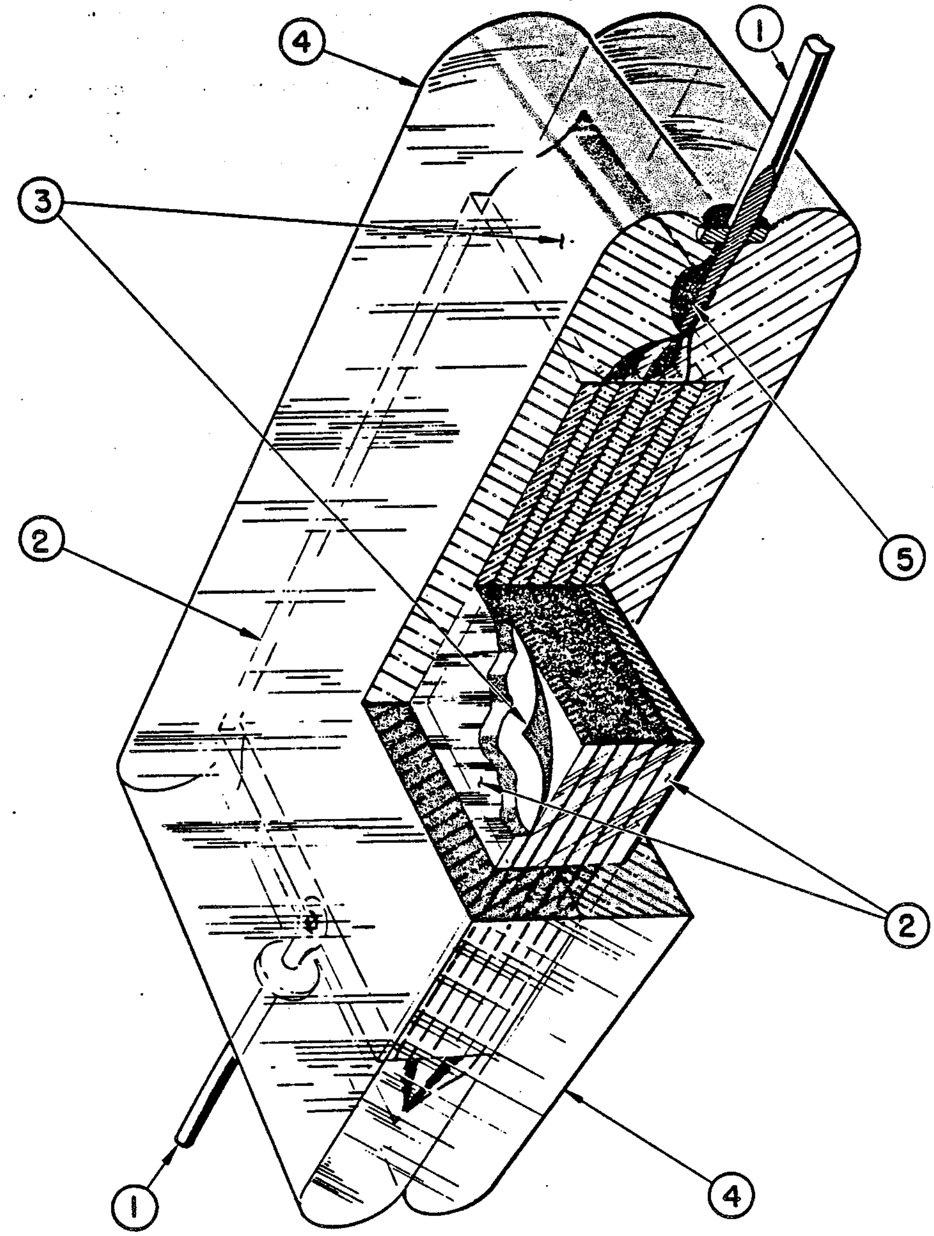

Figure 3-9. Typical Glass Capacitor

ASSEMBLY FLOW

General. With reference to the assembly flow diagram (Figure 3-10), the processing of materials for this type of glass capacitor, once the assembly is started, consists of cutting, stacking, processing, welding, and fusing. The cutting operation may be considered critical from a reliability standpoint. The first cutting operation consists of notching the foil to form the conductive plates. Any rough edges, burrs, slivers, etc., will reduce the dielectric thickness of the finished capacitor resulting in lowering the insulation resistance. A second cutting operation consists of separating the capacitors from a multiple capacitor strip. This operation must be controlled to a tolerance sufficiently close to allow proper case edge thickness following the "clean and cut apart" operation, i.e., the conductive element must be centered in the glass case. Also, the sharpness of the cutters directly affects the degree of chipping and cracking of the glass case and dielectric.

FLOW DIAGRAM			RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL	MANUFACTURING OPERATION	CRITICAL PROCESS	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
Conductor (Foil) — 3	Notch foil	Sharpness of cutters		A, C, D		
Dielectric (Ribbon Glass) — 2	Stack and trim tab	Proper layer registration and cleanliness of cut	A		A1, 3, 7	
Leads — 1	Weld	Weld schedule	A, D			
Cover Glass — 4	Grind					
	Seal	Purity and homogeneity of glass, temperature, time, and atmospheric condition		C, D		
	Isostatic furnace (fuse)	Purity and homogeneity of glass, temperature, time, and atmospheric condition		C, D	B4, 5	
	Clean and cut apart	Sharpness of cutters and accuracy of cut			A5, 6; B5	F
	Sort					
	Label					
	Leak test and final visual					
	Gold plate leads	Cleanliness of plating bath, temperature, time, uniformity of plating thickness				A
	Final Inspection					
	Q.C. Testing (Groups A and B) Additional I.D. as required					
	Final visual					
	Pack and ship					

Figure 3-10. Glass Capacitor - Typical Assembly Flow with Related Problem Codes

GLASS CAPACITORS

FAILURE ANALYSIS TECHNIQUES

General. Failure analysis is performed to establish remedies for the cause of part failure. It is used to define changes (where required) in component application criteria and/or installation and testing procedures. Very often it reveals subtle modifications of materials and processes used in part manufacturing and/or screening that can enhance application capability of the part.

Predominant Failures of Glass Capacitors. The most frequently occurring type of failure has been shorted plates resulting from breakdown of dielectric due to entrapped air in the glass during manufacture, or due to rough edges on the foil as a result of a poor cutting operation.

Dissection Precautions. Capacitors made of transparent glass may not require dissection to determine the cause of failure. However, if required on either transparent or opaque glass, care must be taken to grind and polish with sufficient skill to avoid chipping or cracking the glass. Small increment cuts should be made to avoid grinding through and missing the area of failure.

Failure Analysis Flow. The failure analysis flow (Figure 3-11) is shown only as a guide, and the specific procedures to be followed should be based on the type of failure to be analyzed.

Relationship to Failures. Where it is relevant, each step of the failure analysis procedure (Figure 3-11) is related to one of the four major problem areas and their causes by a coding system which is defined on the foldout in the Appendix. Thus, one experiencing a specific type of failure can identify those steps in the failure analysis most likely to reveal the problem.

TEST/EXAMINATION	PROCEDURE	WHEN FAILURE IS / LOOK FOR	RELATED PROBLEM CODES (see foldout in the Appendix)			
			OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
NONDESTRUCTIVE MECHANICAL						
External Visual Examination	Note all identifying markings and external damage		A	C		A, B, C, F
Radiographic Inspection	If fixed focus X-ray used, photograph in two planes mutually perpendicular to the longitudinal axis. If Vidicon (imaging) used, examine and photograph anomalies as observed. For units that are transparent X-ray is not required. For units with high Pb content in the glass X-ray may be of no value.		A, E	A, C		
PROBLEM AREA VERIFICATION						
NONDESTRUCTIVE ELECTRICAL						
Electrical Measurements	Measure and record capacitance, dissipation factor (DF), dc leakage (DCL), and insulation resistance (IR) (at high and low temperature if necessary)			D	A2; B1, 5; C1, 3; D	
INDUCING FAILURES						
Special Conditioning	Temperature cycling, or vibration only if required to confirm problem area					
Electrical Measurements	Capacitance, DF, DCL, or IR as required					
PROBLEM CAUSE VERIFICATION						
Seal Test	Transparent – 6-1/2 minutes in Zyglo penetrant, including 3 minutes under 20 psig, dry, and inspect under ultraviolet light. Opaque – in saturated steam atmosphere of 5 psig for 20 to 30 minutes		A	D, F	A1, 5, 6; B1, 4, 5, 6; C1, 2, 3; D1	
Dissection and Examination	Put in suitable potting material and dissect. Must be performed in small increments so as not to grind through the failed zone		A, B, D	A, C, D	A1, 3, 4, 5, 6; B1, 2, 4, 6; C1, 3	
Materials Analysis Spectrographic Microprobe	May be performed in conjunction with depotting or dissection. Analyze all foreign material not otherwise identifiable			A, B	A2; B2, 3	A

Figure 3-11. Glass Capacitor - Typical Failure Analysis Flow with Related Problem Codes

ALERT SUMMARIES

Summaries of ALERT reports issued against Ceramic, Solid Tantalum, Wet-Slug Tantalum, Glass, and Miscellaneous Capacitors are shown below. They are listed according to the Problem Area - most frequent to least frequent occurrences, except the Miscellaneous are listed by type. The "ALERT ITEM NO." (first column) references each summary back to the "Problem Area/Cause, and Suggested Action" table.

CERAMIC CAPACITORS

ALERT [1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
1 GSFC-70-04	OPEN Lead separation	Opens or intermittent opens were caused by the separation of leads from the capacitor element.	These failures were caused by the application of excessive soldering heat during assembly of the capacitors into equipment without any provision for protecting the device by thermal shunting.
2 GSFC 8-29-67	OPEN Cold solder connection	During acceptance test, the capacitor was effectively open at 75°C.	Failure analysis revealed an internal cold solder connection between a lead and the edge of the capacitor electrodes. A low temperature (60/40) solder had been used.
3 MSFC 11-13-67	OPEN Inadequate lead bonding	A failure was experienced during temperature cycling.	Failure analysis revealed inadequate lead bonding, little or no solder flow, lead misalignment, and generally poor workmanship.
4 S4-A-72-01	OPEN Broken Leads	Leads broke at swaged round lead transition during installation of capacitors	An X-ray criterion was used to screen out units having less than 0.025 inch of epoxy between the bottom of the ceramic chip and the external surface of the case, but this did not eliminate the defective capacitors.
5 K9-71-21	OPEN Cracked ceramic	Capacitors tested open, short, showed high leakage and out of tolerance capacitance.	Radiographic inspection indicated the ceramic had been cracked during the manufacturer's molding process.
1 GSFC-70-04	SHORT Solder reflow	Shorts were caused by the reflow of solder within the capacitor into voids and cracks in the ceramic dielectric.	These failures were caused by the application of excessive soldering heat during assembly of the capacitor into equipment without any provision for protecting the device by thermal shunting.
5 K9-71-21	SHORT Cracked ceramic	Capacitors tested open, short, showed high leakage and out of tolerance capacitance.	Radiographic inspection indicated the ceramic had been cracked during the manufacturer's molding process.

CERAMIC CAPACITORS

ALERT [1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
6 GSFC-69-13	SHORT Contamination - solder between electrodes	A short was detected in the capacitor during bench test on a breadboard circuit.	Failure analysis disclosed voids in the epoxy seals were filled with solder which bridged the capacitor electrodes. Low melting solder, used internally, flowed into the voids because of excessive soldering temperatures and time during installation of the capacitor into the circuit.
7 GSFC 10-3-67	SHORT Breakdown of dielectric	During a checkout experiment, 140 Vdc was placed across the terminals of the capacitor. A 20 V positive spike (in addition to the 140 volts) existed at turn-on. The capacitor failed in the short mode.	Failure analysis confirmed the short, and internal visual examination revealed a dielectric puncture at the edge of the electrode metallization.
8 G4-A-72-02	SHORT Shorted electrodes	Capacitors failed short during thermal vacuum testing of Earth Sensors.	Failure analysis revealed delamination of the ceramic dielectric element and shorting of the electrodes.
9 5G-70-01	ELECTRICAL PARAMETER DEVIATION - HIGH TEMPERATURE COEFFICIENT Failed temperature coefficient test	Sample piece part testing indicated a temperature coefficient problem when tested to MIL-C-81 (ref 9).	Of the 39 samples tested, 24 exceeded the specified capacitance change.
5 K9-71-21	ELECTRICAL PARAMETER DEVIATION - HIGH LEAKAGE AND CAPACITANCE OUT OF TOLERANCE Cracked ceramic	Capacitors tested open, short, showed high leakage, and showed capacitance out of tolerance.	Radiographic inspection indicated the ceramic had been cracked during the manufacturer's molding process.
10 J5-72-01	ELECTRICAL PARAMETER DEVIATION - LOW INSULATION RESISTANCE Deformed plates	Capacitors demonstrated low IR when tested at high temperature.	Manufacturer believed that the pressure used when fixing the green ceramic into the monolithic block was too great.

CERAMIC CAPACITORS

ALERT [1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
11 GSFC-71-01	ELECTRICAL PARAMETER DEVIATION - LOW INSULATION RESISTANCE Breakdown of dielectric	Capacitors were rejected for failure to meet the specified 1000 megohm insulation test.	The manufacturer stated the problem was associated with a single batch of defective ceramic.
12 B1-68-02	EXTERNAL MECHANICAL ANOMALY Damaged leads	Capacitor lead cracking occurred during welding, producing unsatisfactory cracked welds.	Failure analysis of leads with high tensile strength showed chemical analysis conforms to MIL-STD-1276 (ref 6). However, tensile strength tests showed "hard" leads to be 112 kpsi instead of 82 kpsi. Residual stress was retained in the lead wire because of inadequate annealing after cold working.
13 S4-69-01	EXTERNAL MECHANICAL ANOMALY Cracked case	Fractures were observed in the cases of large case size capacitors after the equipment was subjected to temperature cycling.	These fractures only happen on large case size units and only if the ratio of resin and epoxy is incorrect, or if they are not completely mixed.
14 B2-A-72-45	EXTERNAL MECHANICAL ANOMALY Improper marking	Tape recorder malfunctioned during functional test.	Failure analysis revealed that 0.01 μF capacitors were mislabeled as 0.1 μF. Cross sectioning of one improperly marked capacitor and one properly marked capacitor showed a difference in the number and spacing of the plates.

SOLID TANTALUM CAPACITORS

ALERT [1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
15 D5-68-01, 01A	OPEN Termination metallization separation (slug to case)	Capacitor failed during vibration test.	Failure analysis revealed an inadequate solder bond between the slug and the base of the capacitor. This resulted in failure (open) during vibration testing.
16 T9-A-72-01	OPEN Lead separation	Radiographic inspection of capacitors revealed a dual lead between pellet and end cap, a fractured internal lead, and a defective weld.	Failure analysis by the manufacturer revealed the problems were caused by human error, and damage.

SOLID TANTALUM CAPACITORS

ALERT [1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
17 BBRC-68-01	SHORT Breakdown of dielectric	One capacitor tested short upon receipt. Another shorted after 100 hours of additional screening at 50 Vdc at 85°C.	Failure analysis disclosed a direct short through dielectric film with evidence of high current after initial dielectric breakdown (caused by burn-in power supply through slo-blo fuse). Flaws not picked up during initial screenings, or that deteriorated with time, were probable cause of breakdown.
18 K9-71-03	SHORT Contamination - internal solder balls	Radiographic inspection of capacitors disclosed internal solder balls.	Solder balls were caused during lead tinning operation which melted the internal solder. It was established that the capacitor leads were immersed into the solder pot too close to the capacitor body.
19 MFSC-71-03, 03A, 03B	SHORT Contamination - solder between tubelet and case	Capacitor shorted due to reflow of internal solder.	Investigation revealed solder from the tubelet had melted and flowed internally between the tubelet and case, causing a short. Excessive heat during retinning of the lead, installation on the board, or rework of the board solder connection was indicated.
20 J5-70-01, 01A	ELECTRICAL PARAMETER DEVIATION - HIGH DC LEAKAGE Wrong anodes	Leakage current exceeds specification in 35 to 100 percent of devices following burn-in.	Information received from manufacturer indicates that 35-volt anodes were used instead of the 100-volt anodes which should have been used.
21 R4-71-01, 01S	ELECTRICAL PARAMETER DEVIATION - HIGH DC LEAKAGE Breakdown of dielectric	Capacitors exhibited high dc leakage, larger than typical dc leakage versus temperature, and unstable dc leakage.	Problems were caused by marginal performance parts coupled with overstressed test conditions by the user.
22 L1-70-01	ELECTRICAL PARAMETER DEVIATION - HIGH DISSIPATION FACTOR Poor solder bonds	Several capacitors exhibited increasing dissipation factors subsequent to shock testing.	Failure analysis of three units showed a poor solder bond to the anode. No other discrepancies were noted. It was concluded that the increasing dissipation factor was due to poor solder bonds to the silver-coated anodes.

WET-SLUG TANTALUM CAPACITORS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
23 MSC-68-11	ELECTRICAL PARAMETER DEVIATION - HIGH DC LEAKAGE Incorrect tantalum risers - LOW CAPACITANCE Improper cathode preparation	A high failure rate (47 failures out of 325 parts) resulted in the entire lot being rejected.	Failure analysis revealed that the leakage current failures were caused by incorrect length tantalum risers, and that capacitance loss was caused by improper preparation of the cathode.
24 GSFC 10-31-67	ELECTRICAL PARAMETER DEVIATION - HIGH DC LEAKAGE Electrolyte leakage	Subject capacitor developed excessive leakage current during vacuum temperature cycling.	Failure analysis determined that electrolyte was leaking through the teflon seal and being trapped under the epoxy coating creating a dc leakage path from the lead weld to the case. The electrolyte leakage about the lead was caused by different expansion coefficients between the Teflon and the lead.
25 LeRC 7-18-66	ELECTRICAL PARAMETER DEVIATION - HIGH DC LEAKAGE Defective internal seal	During and after random vibration, subject capacitors were observed to go out of specification on dc leakage.	Investigation revealed an electrical leakage path from the anode to the case created by electrolyte migration through the elastomer bushing. It was also noted that the capacitor is of marginal design in that the slug is not always held firmly in place by the retainer cup, allowing the slug to oscillate during vibration and pump electrolyte through the bushing.
26 CG-70-02	OPEN Lead separation	Failure of a printed wiring board was traced to a faulty capacitor.	An investigation showed that the external weld on the anode lead had separated.
27 KSC-71-05	EXTERNAL MECHANICAL ANOMALY Defective seal	Visual inspection of a failed capacitor indicated electrolyte leakage.	Failure analysis confirmed the leakage which was caused by deformation of the Teflon sealer probably resulting from crimping the case during fabrication.
28 F3-72-02	EXTERNAL MECHANICAL ANOMALY Defective seal	Capacitors' glass headers leaked acid.	The manufacturer confirmed that over etching (a lead cleaning operation) caused the failure.
29 S8-A-72-02	EXTERNAL MECHANICAL ANOMALY Defective seal	Several capacitors were found leaking around the seal area.	The manufacturer stated the problem was due to a worn die in the closing machine.
30 MSFC-72-03	EXTERNAL MECHANICAL ANOMALY Defective seal	Electrolyte was found leaking from a capacitor.	Failure analysis showed leakage paths occurring under, around, or through the brazing material used for the final sealing.

GLASS CAPACITORS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
31 D4-70-04	OPEN Lead not fused to plates	The capacitor would open at approximately 90°F and above.	Failure analysis revealed that one lead was not fused to the plates. The method of lead attachment is by pressure and heat. Indentation on the plates indicated that pressure had been applied but apparently no fusion took place. Operation of the capacitor at elevated temperatures caused an open.
32 GSFC-68-05	ELECTRICAL PARAMETER DEVIATION - HIGH SERIES RESISTANCE Void between end cap and capacitive element	Capacitor failed during a thermal cycling test.	Failure analysis of the capacitor revealed a 1000 ohm series resistance. Analysis and examination of the failed capacitor and other capacitors, revealed voids between the end cap and capacitive element.
33 D7-71-02	ELECTRICAL PARAMETER DEVIATION - LOW CAPACITANCE Decrease in dielectric constant	Glass capacitors were rejected because the capacitance value was below that specified.	During storage at a temperature below the Curie point (45°C) there is a decrease in the dielectric constant due to a change in the crystalline structure of the dielectric which causes a decrease in capacitance. Failure analysis by the manufacturer revealed that the production guard band for capacitance value sort was insufficient to preclude aging rejects for "V" characteristic capacitors.

MISCELLANEOUS CAPACITORS

TYPE; ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
AIR, VAR 34 L9-70-01	OPEN Poor stator terminal solder connection	Trimmer capacitors exhibited intermittent failure.	Failure analysis revealed a low quality solder connection inside the capacitor. Reflow of the connection because of wave-soldering the assembly caused the connection to degrade further.
AIR, VAR 34 L9-70-01	UNADJUSTABLE Contamination - solder resin in moving parts	Trimmer capacitor would not adjust.	Solder resin was found in moving parts. Analysis indicated resin was present prior to installation.
AIR, VAR 35 JPL-68-02	SHORT Contamination metal particles within the capacitor	Short circuits occurred in three capacitors subjected to subsystem vibration.	Examination of the capacitors revealed metal particles within the interior of the capacitor, determined to be due to thread galling and flaking. The thread wear developed under normal adjustment procedures and is directly related to the quality of the threading and the quality of the gold plating.

MISCELLANEOUS CAPACITORS

TYPE; ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
AIR, VAR 36 GSFC-68-10	SHORT Deformed plates	Repetitive alignment problems and excessive currents upon initial turn-on were experienced with transmitter assemblies.	Internal examination revealed that the plastic insulator disk used as a "stop" had slipped out of position and was jammed between the stator and rotor cylindrical plates causing them to deform and short. Additional investigation disclosed that the plastic "stop" diameter was smaller than required to provide a press fit with the center rotor cylinder. This condition was attributed to shrinkage of the plastic after the punching operation.
ALUM, ELECT 37 GSFC 4-8-66	OPEN Internal lead separation	During sine wave vibration at 20 g (peak-to-peak) the capacitor failed as an open.	Lack of end spacers caused motion of the rolled foil inside the capacitor case. After a redesign, using slightly compressed end spacers, the vibration problem was solved. However, a chemical reaction between the electrolyte and the plastic end spacers caused the capacitor to fail in life testing.
ALUM, ELECT 38 KSC-71-07	OPEN Internal lead separation	Capacitor in an audio amplifier failed.	Failure analysis revealed an open circuit at a point where the positive electrode first encounters the electrolyte. Cause was an electrochemical reaction in which the lead between the positive electrode and the aluminum electrode is dissolved.
ALUM, ELECT 39 R8-69-01	SEAL DEGRADATION Incompatibility of materials	Use of a halogenated solvent wash can cause deterioration of the elastomer end seal.	Aluminum electrolytic capacitors manufactured in accordance with MIL-C-39018 (ref 10) are exposed to subsequent increased failure liability by subjecting them to any type of halogenated solvent wash. This failure mechanism is temperature, voltage, and time dependent. The risk of failure can be reduced by strict process control of the wash cycles combined with the use of an epoxy barrier over the positive end seal of the capacitor.
MET-FILM 40 R4-A-72-01	EXTERNAL MECHANICAL ANOMALY Improper marking	Two lots of capacitors were received with interchanged voltage.	Some 600 Vdc capacitors were marked with the code for 200 Vdc, and some 200 Vdc devices were marked with the code for 600 Vdc.
MET-MYLAR 41 D5-A-72-01	OPEN Lead separation	Capacitors exhibited intermittent open circuit during package or system level test.	Failure analysis revealed the bond between the lead spiral and metal end spray was broken. X-ray examination prior to disassembly was found to be inconclusive as to the integrity of the end connection.

MISCELLANEOUS CAPACITORS

TYPE; ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
MET-PAPER 42 JPL 5-11-66	OPEN Internal lead broken	Capacitor failed (open) during vibration test.	Internal visual inspection revealed that lead wire had broken at the point where the lead wire passes through the metal eyelet in the glass end seal. This condition was caused by loose construction of the capacitor element. Vibration tends to cause intermittent and open circuits.
MICA 43 GSFC-68-08	ELECTRICAL PARAMETER DEVIATION - INSTABILITY Damaged lead-tin contact foil	Instability in a subcarrier oscillator was traced to two faulty capacitors.	Failure analysis of the miniature, single dip-coated mica dielectric capacitors revealed damaged lead-tin contact foil. This problem is attributed to exposure to excessive temperature during soldering the units into the equipment. The miniature, thin-walled units are more susceptible to such damage than the larger, heavily-coated MIL-C-5 (ref 11) styles. If the miniature must be used, silver contact foil should be specified and heat-sinking provided during soldering operations.
MYLAR FOIL 44 MSFC 10-3-67	OPEN Improper bonding, lead-to-foil	Capacitor intermittently open.	Failure analysis revealed that the capacitor had inadequate bonding (little or no solder) of the pigtail to the capacitor foil, resulting in intermittent or permanent open circuit when subjected to vibration.
PAPER 45 LeRC 12-7-64	OPEN Improper bonding, lead-to-foil	Capacitors exhibited intermittent open during vibration testing.	Failure analysis revealed that the capacitor failed in an intermittent open mode at the lead-to-foil junction. Manufacturer states that the problem is due to poor workmanship associated with improper heat adjustment and insufficient swaging compound.
POLYSTYRENE 46 GSFC 4-8-66	OPEN Improper lead attachment	Capacitor developed intermittent open during temperature cycling test between +25°C and +50°C. Intermittent condition lasted for periods of 10-15 seconds during temperature transitions.	Failure analysis revealed poor resistance weld between the capacitor lead and the tab insert. The lead was resting on the insert so that a mechanical contact was made. Under thermal stress, the tab insert would bend away from the lead causing the open circuit.
POLYSTYRENE 47 F6-68-01	SHORT Breakdown of dielectric	All capacitors tested shorted when received in a lot of 75 each, and a lot of 49 each.	Failure analysis disclosed a direct short through dielectric films. If capacitors exceed 85°C, permanent damage can result.

MISCELLANEOUS CAPACITORS

TYPE; ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
TA FOIL 48 F3-72-03	OPEN Lead separation	Leads fell off a capacitor.	Manufacturer used incorrect weld schedule to butt weld replacement leads.
TA FOIL 49 MSC 11-15-65	SHORT Electrolyte leakage	Capacitors short as a result of 125°C thermovacuum test.	The tantalum connecting lead wire is soldered to a nickel wire internal to the capacitor. It is at this point (between the nickel anode wire and case) that a short circuit is produced when sufficient electrolyte leakage occurs through the center of the seal.
TA FOIL 50 GSFC 6-22-67, Add 7-6-67	ELECTRICAL PARAMETER DEVIATION - HIGH DC LEAKAGE Internal seal defective	Approximately 25 percent of 150 units submitted to incoming inspection exhibited excessive dc leakage between insulated terminals and case.	Manufacturer attributes the dc leakage to improperly cured insulating material on the internal surface of the glass sealed header allowing electrolyte to escape from the inner case.
TA FOIL 51 GSFC-71-06	ELECTRICAL PARAMETER DEVIATION - HIGH DC LEAKAGE Contamination - metallic particles in the mylar sleeving	Capacitors displayed low terminal-to-case insulation resistance.	Failure analysis revealed: (1) a metallic contaminant embedded in the mylar sleeving insulating internal metal-cased capacitor elements from the outer metal can, and (2) the internal epoxy potting compound was tacky and poorly cured. A 398°K bake for one hour cured the epoxy.
TA FOIL 52 J5-68-01	ELECTRICAL PARAMETER DEVIATION - LOW CAPACITANCE Faulty anode lead-to-foil welds	Of 55 units tested, 35 failed after burn-in due to low capacitance.	Failure analysis attributed the problem to machine and operator error.

NOTE:
1. Where no ALERT number (GIDEP) exists, the originator and date are shown.

SECTION 4
CONNECTORS
(GIDEP CODE 201)

CONTENTS

INTRODUCTION

OBJECTIVE

The objective of this section is to identify the major problem areas associated with the use of connectors and to suggest approaches (developed from experience) for dealing with those problems.

SECTION ORGANIZATION

The connector section is presented with the following organization:

General

Basic failure problems associated with connectors are identified based upon ALERT and industry experience.

Subtopics - Treatment of Specific Types

1. Connector type background.
2. For those in the process of selecting parts and manufacturers or attempting to eliminate part problems at the manufacturer levels, a portion is devoted to describing the inner construction of one selected type. Particular emphasis is given to the design or manufacturing deficiencies associated with the identified failure mechanisms.
3. Basic approaches are provided to assist in developing a competent failure analysis plan where corrective action at the part level is desired. The material is arranged so that one experiencing a specific problem can identify those steps in the failure analysis process likely to reveal that problem.

Connector Types. Connectors have been divided into subtopics according to their physical configuration. Cylindrical multipin and RF connectors have been discussed in depth as they are the types most commonly used in equipments. Other subtopics dealing with adapter, rectangular, etc. type connectors include only summaries of ALERT reports.

FAILURE MODES

Failure Categories. Part level failure problems associated with connectors may be lumped under four basic categories: catastrophic opens, catastrophic shorts, mechanical and electrical parameter deviation, and mechanical damage. It must be recognized that catastrophic opens and shorts are worst-case conditions of certain electrical parameter deviations.

ELIMINATING DEFECTIVES

Problem Solving Approach. The approach taken in this section will be to identify the user-encountered problem areas associated with a particular type of connector, then provide suggestions for eliminating those connectors prone to exhibiting such problems at the finished connector level, the design level, and at the manufacturing level.

Design Level. Certain design compromises are inevitable, however, reliable equipment can be built if these compromises are recognized and proper precautions are taken in the equipment design to minimize the effects of these compromises. Design deficiencies must be identified and eliminated at the manufacturer's facility.

Manufacturing Level. The most carefully conceived design can be brought to nought if it is manufactured in an environment lacking necessary controls over critical materials and processes and allowing substandard workmanship. The technique for removing those potential reliability degraders is to take action to correct the manufacturing conditions by applying controls and providing inspection points.

FAILURE ANALYSIS

Objective. A primary objective of failure analysis is to identify failure mechanisms at a level such that corrective action is feasible. Knowing nothing more about a connector than that it is shorted does not allow effective corrective action. If we learn that the open is caused by silver sulfide, we now have identified a mechanism suitable for corrective action. The silver can be eliminated, or the conditions that enhance creation of the sulfide can be controlled.

Failed Part Rarity. A part in a failed condition must be considered by its owner as a jewel, a "once-in-a-million" occurrence, a phenomenon he may never again be privileged to witness. Only if one starts from that position may there exist a reasonable chance of performing a successful failure analysis.

Failure Verification. After recording all identifying external markings, and performing a thorough external and radiographic inspection, the first requirement is to verify the failure. Too often the wrong part is removed from the circuit, or an equipment test error, rather than a part failure, results in a good part being delivered for failure analysis.

Analysis Direction. The process of analyzing a failure, performing those steps necessary on a suspect device which will result in the identification of a specific correctable failure mechanism, requires the coordination of a series of specialized skills by one having knowledge of failure mechanisms, device design, and manufacturing techniques; and the experience necessary to organize this combination of skills and knowledge into a practical plan of action.

When to Analyze. Many part failures occur for which no corrective action is planned to be taken. In many cases it is most cost effective to simply scrap the defective part and replace it with one that performs properly. Where it is necessary to have assurance that future failures will not occur, a portion of this section is devoted to describing some of the considerations involved in performing effective failure analysis.

Reliability/Life. It is anticipated that as a result of this series of actions at the part level (analysis of design and manufacturing, and effective failure analysis), that significant improvement in reliability and life will be realized.

TECHNIQUES FOR REDUCING CONNECTOR MALFUNCTIONS

General. The majority of connectors are supplied to users as unassembled groups of component parts in order that they may be assembled onto wires or other system components. It follows that screening in the usual sense is a fruitless procedure as the findings are invalidated by the subsequent disassembly for incorporation into the final configuration. On the otherhand, a review of the ALERT reports found in this section will reveal that the reported malfunctions fall into four broad categories: (1) design inadequacies, (2) manufacturer process control, (3) installation procedures, and (4) installation/rework tooling, and if the problems can be properly categorized, they should be amenable to control or correction.

The techniques required, in their order of application, are: configuration analysis, meaningful inspection at time of receipt, adequate failure analysis, and maintenance of a good failure history.

Configuration Analysis. The first item consists of ascertaining the construction and geometrical arrangement of the component parts of the connector in the final assembled form plus the materials of construction, including platings, of each component. This information is assessed to determine the possibility of enhancement of corrosion and other forms of degradation caused by the presence of materials that can exude attacking monomers and compounds such as sulphur. The possibility of galvanic corrosion can also be determined at this time. Furthermore, this information is the basis from which application notes and incoming inspection instructions are prepared.

Receiving Inspection. Meaningful inspection at time of receipt is more than a mechanical check of identification and damage. A review of the information obtained by configuration analysis will reveal other significant items that must be controlled, such as thickness and porosity of gold plating on pins and contacts. Control of gold plating on incoming items is only afforded by destructive metallurgical analysis on a sampling basis.

Failure Analysis. Analysis of failed or malfunctioning connectors is too often limited to disassembly/dissection of the failed device. As connectors are normally assembled and installed by the user, it is cogent to review the history of the connector with respect to prior storage, assembly, and usage. For frequently it is only by this comprehensive review that the true cause of a so-called "shop error" can be traced to a design inadequacy or manufacturer processing error, rather than inadequate shop instructions, procedures, or tools.

Failure Records. Every known failure and malfunction of a connector should be recorded in one central location with respect to actual cause of failure as determined by competent analysis, plus identity of connector and vendor. Periodically, histograms should be constructed for those failures associated with each device. Systematic review of this information can lead to design modifications, improvement in manufacturer's process control, and improvement in shop procedures and tools.

CYLINDRICAL MULTIPIN AND RF CONNECTORS,

CHARACTERISTICS

Basic Considerations. A connector is a device consisting of a plug and a receptacle that provides a mechanical disconnect ability between the various components/subassemblies within an electrical circuit. To insure reliability, the completed connection must be electrically and mechanically stable. Mechanical instability can contribute to subsequent malfunctions such as increased resistance, intermittents, opens, etc. The connector plug or receptacle is the termination of internal circuit leads and/or cables. Connections are made to the individual wires by crimping, soldering, welding, and/or the clamping action of internal mechanical closures. The coupling system between the plug and receptacle of a connector typically is one of several styles: push-pull, bayonet, screw-on, or rack and panel. Connectors are available in various configurations such as cylindrical multipin, RF, NEMA (household appliance type), rectangular, and printed wiring types.

In order to give the reader some insight into the differences that may be encountered, the two types most commonly employed in aerospace systems, cylindrical multipin and RF, are briefly discussed below.

Cylindrical Multipin Connectors. Cylindrical multipin connectors consist of a regular array of individual contacts within a cylindrical protective shell. The most common construction provides for connection by entry of a pin contact into a female socket contact for each circuit. The pins are mounted in the plug or receptacle connector section by implanting into an insulation insert that may be firm or resilient. The female socket, consisting of a tubular insert or holder that contains a contacting spring, is also mounted in the plug or receptacle connector section by implanting into an insulation insert that may be firm or resilient. Positive mating retention between plug and receptacle is provided, generally, by a locking mechanism, such as bayonet, push-pull or engaging screw threads. (The physical arrangement of these components may be seen in the exploded view of a typical connector found in Figure 4-1.) The pins and socket components may or may not be removable and replaceable. In the event that localized repair cannot be accomplished by replacement of one of these components, inadvertent damage to only one pin or socket can cause the replacement of the entire unit.

One of the primary characteristics of this type of device is that all connections must be made simultaneously. Cocked, bent, or broken pins or contacts can result in a malfunction. An obvious disadvantage is that minute contamination within a female contact would not be visible, but could result in an open circuit condition and/or damage to the contacting surface of either the pin or contact.

RF Connectors. RF connectors normally consist of only one pin and socket connector co-axially mounted within a metallic protective shell that also serves as a shield against stray electrical fields. The other physical features are similar to the above description of the cylindrical connector with exception of construction of the female contact and rigidity of insert material. The female contact is normally a simple split cavity within the approximate center of the contact, and the required flexure is limited by the resiliency of the center contact material. Usually the insulation insert tends to be firm.

CYLINDRICAL MULTIPIN AND RF CONNECTORS
DESIGN AND PRODUCTION CONSIDERATIONS

Design Considerations. Significant consideration that must be observed in the design of connectors include the following:

1. Adequate conductivity.
2. Surfaces that are resistant to corrosion, tarnishing, and attack by any component of the environments that will be encountered during the life of the device.
3. Surfaces that are resistive to degradation by abrasion.
4. Inherent positive mechanical stability.
5. Configuration to minimize entry of possible contaminants, including moisture and degrading gases.
6. Physical design that minimizes inadvertent damage at time of installation and/or subsequent connection/disconnection operations. Not to be overlooked, the design should be amenable to economical repair.

Fabrication Considerations. From the information at hand, the following areas are those over which the manufacturer must maintain stringent control: contaminants, potting mixing and application, dimensions of finished components, and plating procedures. The most significant of this is plating for without adequate control, the plating can be friable, porous, or too thin. Any of these conditions can increase the possibility of abrasive damage and/or corrosion.

Installation Considerations. As connectors are generally supplied to the user as groups of individual components that are assembled onto the appropriate wire to form a connector, a significant amount of the difficulties encountered with connectors are created at time of installation. The use of improper or wrong tools often results in bent pins, cracked or split insulation inserts, etc. which result in subsequent malfunctions. It is imperative for the successful use of connectors that the installing personnel be properly instructed and be supplied with appropriate tools.

Special Parameters. The above discussion has served to define application limitations of connectors related to physical characteristics associated with the materials used and with techniques used in the manufacture and installation of the devices. These limitations can be described as specification limits and application notes for use by manufacturers and using designers. Deviations from these limits can lead to equipment failure. The next subsection will describe problems and failure mechanisms found in connectors caused by design deficiency, lack of process control, and inadequate quality control.

TYPICAL CYLINDRICAL MULTIPIN CONNECTOR DESIGN (Figure 4-1)

ITEM NO.	ITEM NAME	MATERIAL OF CONSTRUCTION
1	Plug Shell O-Ring	Silicone rubber
2	Socket Contact Body	Leaded copper
3	Socket Contact Spring	Leaded copper
4	Pin Contact	Beryllium copper
5	Contact Retaining Sleeve	Beryllium copper
6	Front and Rear Insert	Transfer moldable plastic
7	Grommet	Silicone rubber
8	O-Ring	Silicone rubber
9	Retaining Nut	Aluminum alloy

ITEM NO.	ITEM NAME	MATERIAL OF CONSTRUCTION
10	Insert Retaining Spring	Beryllium copper
11	Seal	Silicone rubber
12	Snap Ring	Corrosion resistant steel
13	Mounting Washer	Aluminum alloy
14	Mounting Nut	Aluminum alloy
15	Receptacle Housing	Aluminum Alloy
16	Insert Seal	Silicone rubber
17	Follower	Aluminum alloy
18	Plug Retaining Nut	Aluminum alloy
19	Plug Shell	Aluminum alloy
20	Washer	Teflon
21	Locking Spring	Aluminum alloy
22	Coupling Ring	Aluminum alloy
23	Rear Coupling Ring	Aluminum alloy
24	Front Coupling Ring	Aluminum alloy

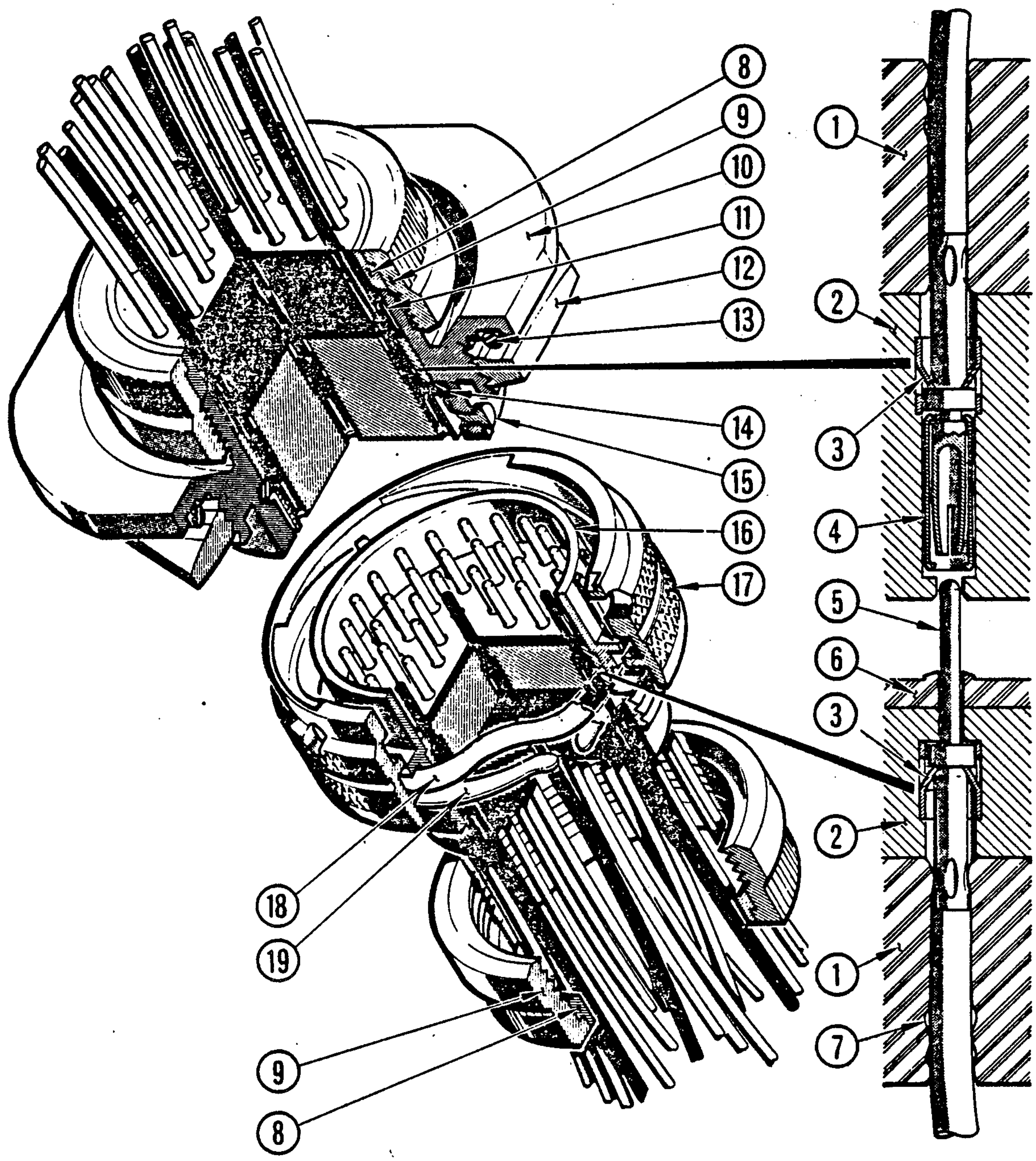

Figure 4-1. Typical Cylindrical Multipin Connector

CYLINDRICAL MULTIPIN AND RF CONNECTORS

FAILURE ANALYSIS TECHNIQUES

General. Failure analysis is a corrective action procedure. Only after knowing why a part failed can action be taken to minimize future failures. The results of failure analysis can show the need for redesign, improvement in installation and esting techniques, changes in application information, and/or modification of the basic part by improvement of materials, processes and control thereof as used in the fabrication of the part.

Predominant Failures. The principal failure mode for all connectors is an open condition. The open condition is generally caused by contamination interfering with the normal operational mode of the contacts.

Failure Analysis Flow. The failure analysis flow diagram (Figure 4-2 which follows) provides for maximum nondestructive evaluation of the suspect part prior to application of any destructive techniques.

Relationship to Failures. Where it is relevant, each step of the failure analysis procedures (Figure 4-2) is related to one of the four major problem areas and their causes by a coding system which is defined on the foldout in the Appendix. Thus, one experiencing a specific type of failure can identify those steps in the failure analysis most likely to reveal the problem.

TEST/EXAMINATION	PROCEDURE	WHEN FAILURE IS / LOOK FOR	RELATED PROBLEM CODES (see foldout in the Appendix)			
			OPEN I	SHORT II	PAR DEV III	MECH DAM IV
NONDESTRUCTIVE MECHANICAL						
External Visual Examination	Record all identification marks and damage (photographs preferred)		E	A,B		A,B,C, F,G
Radiographic Inspection	If fixed focus X-ray is used, photograph in two mutually orthogonal planes as required to record any interior anomalies. If Vidicon (imaging) is used, examine and record anomalies as observed		A,B,C, E,G,H			
PROBLEM AREA VERIFICATION						
NONDESTRUCTIVE ELECTRICAL						
Parameter Verification	Verify values of all parameters using methods as described in the applicable specifications. These tests should be performed in the as-received condition, either in the mated or de-mated state, and then repeated in the opposite state as applicable. The mechanical parameters, such as separation force, should be performed as an adjunct to these tests		all	all	all	
INDUCING FAILURES						
Conditioning	Temperature cycling, vibration, immersion and exposure to high humidity, shock, etc., only if required to confirm problem area					
Parameter Verification	Repeat applicable parameter verification tests and record any observed changes		all	all	all	
PROBLEM CAUSE VERIFICATION						
Disassembly	Progressively disassemble and record all observed anomalies		all	all	all	
Particle Retrieval and Examination	Solvent clean all component parts of the disassembled connector and recover all dislodged films and particulate material. Identify constituent materials of the dislodged materials and their source		C,H	A	A,C	A,C,G
Dissection	Metallurgically section components as required to provide positive identification of voids, weld defects, plating anomalies, etc.		A,C,H	A,B		G
Materials Analysis Microchemistry Microprobe Spectrographic	May be used in conjunction with any of the foregoing destructive analysis techniques. Analyze all foreign material not otherwise identifiable		A,C,H	A,B		G

Figure 4-2. Cylindrical Multipin and RF Connectors - Typical Failure Analysis Flow with Related Problem Codes

ALERT SUMMARIES

Summaries of ALERT reports issued against Cylindrical Multipin, RF, and Miscellaneous Connectors are shown below. They are listed according to Problem Area-most frequent to least frequent occurrences, except the Miscellaneous are listed by type.

CYLINDRICAL MULTIPIN CONNECTORS

ALERT NO.[1] (GIDEP)	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
ARC 4-3-67	OPEN Defective component	A discontinuity was found in one pin during systems test.	An over-drilled solder well in a connector pin resulted in collapse of the pin during original fabrication of the connector. Continuity was provided by "friction" contact between the two broken sections. The continuity was destroyed during incorporation of the defective connector in aerospace equipment.
S9-71-01, S9-72-01	OPEN Defective component	Pencil clip retention mechanism was found to be improperly formed on the female contacts.	The clip was caused to lie in one of the two following improper positions in relation to the contact, resulting in an open. 1. Too far into the contact, allowing the mating connector to crush it. 2. Not placed far enough into the contact.
MSFC-A-72-11	OPEN Defective component	A discontinuity was discovered during functional test.	Engagement ends of five socket contacts (split tine, open entry type) were spread resulting in zero withdrawal forces causing discontinuity. Contact cavities in hard plastic insert of connector prevents entrance of oversize pin contacts or test probes.
MSC-68-09	OPEN Application problem	Pin collapsed after melting.	Improperly sized circuit breaker failed to trip during probe testing of pin.
MSC-68-05	OPEN Incorrect part used	Connector parts would mate mechanically but would not provide electrical continuity.	Two pin containing plugs were inadvertently connected with a screw-on coupling.
MSFC-68-22	OPEN Contamination	Electrical discontinuity was observed after mating of connector.	Connector pins were coated with Carnuba wax for lubrication.
D4-70-3, 3A	OPEN Installation procedures	Excessively recessed pin contacts in inserts.	Solder procedures other than those recommended by manufacturer can soften adhesive used to secure location of pin contacts. This can result in axial relocation of the inserts.

CYLINDRICAL MULTIPIN CONNECTORS

ALERT NO.[1] (GIDEP)	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
G4-A-72-01	OPEN Installation procedure	Connectors with back-loaded insertable contacts are subject to contacts recessing if not properly seated.	Improper seating can result in open or short circuit.
KSC 3-30-67	OPEN Missing parts	Open within circuit caused equipment malfunction.	One pin in plug had less retention than other pins in same plug. Comparison of the removed pin with similar pins revealed that the retaining ring within the pin was missing.
SMD-68-075	OPEN Inadequate design	Contact pin fails to contact socket properly.	The pins and sockets of this connector are fixed by hard potting resulting in the pin contacting only the retention spring. The retention spring has a high resistance.
MSC-71-01	OPEN Inadequate design	Connector failed intermittently open in the shield circuit.	Investigation revealed the crimp support sleeve had been finger tightened, the thread utilized is a 12-28 with 1-1/2 threads of engagement, and a star type lockwasher is the locking device. Manufacturer has redesigned the connector with a finer pitch thread, no locking device, and a specified torque value.
MSFC-72-04	OPEN Inadequate design	Misalignment of pins and sockets occurs when using coupler adapters from one manufacturer to couple connectors from a different manufacturer.	Worst case tolerance build-up occurs wherein the pin contacts may not engage the spring member of the socket contacts. Situation is caused because the critical mating dimensions are controlled differently - receptacle controlled from the nose of the connector while the adapter is controlled from the rear of the device.
KSC 9-16-64	OPEN Contamination	Silver sulfide film found on surface of gold-plate	When gold is plated over silver, the silver tends to slowly diffuse through the gold. With time, a thin film of silver will form on the surface. Exposure to the atmosphere normally presents enough sulphur to form silver sulfide.
MSC-71-02,02A	OPEN Incorrect part dimensions	Connector pin would not mate with the socket in the mating connector.	The distance between pin end to shell face was in excess of that specified. Investigation by the manufacturer disclosed that improper manufacturing, inspection, and test procedures had been used.
MSFC-71-05	OPEN Incorrect part dimensions	Five contacts could not be inserted in the holes in a CV type connector insert.	Analysis revealed the contact retention shoulders were oversize.

CYLINDRICAL MULTIPIN CONNECTORS

ALERT NO.[1] (GIDEP)	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
MSC 10-11-66	SHORT Contamination (moisture)	An equipment fire resulted from loss of hermeticity and resulting entry of moisture.	Potting, used to seal out moisture, was faulty and not properly bonded because embedded Teflon coated conductors were not etched. Evidence of moisture was found adjacent to connector pins.
D4-69-01	SHORT Contamination	Pin shorted to connector shell by metallic sliver.	X-ray examination of the defective connector revealed a metallic sliver in the silicone insulation insert.
D7-70-02	SHORT Broken component	Broken tine of retention clip shorted pin to connector shell.	Analysis established that a defective removal tool was being used and was causing multiple varieties of damage to the retention clips.
G2-70-01	MECHANICAL PARAMETER DEVIATION - LOSS OF HERMETICITY Bond failure	Socket seal bond failed because of contamination.	Gross leakage around sockets occurred as a result of failure of the socket seal bond. Investigation revealed that failure was caused by improper cleaning at time of application of adhesive, which resulted in entrained contamination.
KSC 12-13-67	MECHANICAL PARAMETER DEVIATION - LOW RETENTION FORCE Defective component	Shell rotated because of faulty preload coupling springs	Improper heat treating of preload coupling springs resulted in the springs taking a permanent set.
MSFC-71-15	MECHANICAL PARAMETER DEVIATION - LOW RETENTION FORCE Defective component	Polarizing index pins fell out of connectors subjected to vibration	The polarizing pin did not have sufficient retention to withstand specified vibration levels.
F3-68-01, F3-68-02	MECHANICAL PARAMETER DEVIATION - LOW RETENTION FORCE Defective components	Improper locking action observed during pre-flight check	Dissection of a connector revealed detent holes in the coupling nut were not located or shaped in accordance with specification requirements.
B8-69-01	MECHANICAL PARAMETER DEVIATION - EXCESSIVE MATING FORCE Process out of control	Connectors were difficult to mate	Defective manufacturing processes, including dimensional discrepancies and plating variations, resulted in difficulty when assembling the mating connector.

CYLINDRICAL MULTIPIN CONNECTORS

ALERT NO.[1] (GIDEP)	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
K4-71-03	MECHANICAL PARAMETER DEVIATION - CONNECTOR COMES APART Inadequate design	Coupling rings fell off connectors during mating	When the minimum interference fit (C-ring into coupling ring groove) is approached, the connector thrust washer has a diametrical movement, which combined with the egg-shaped distortion of the coupling ring during mating, results in the C-ring unseating and the connector falling apart.
MSC 10-7-65	MECHANICAL DAMAGE Contamination (corrosion)	Gold-plated pins were discolored by a black film (silver sulfide).	Protective cap that is placed over open connector ends when connector is disengaged was fabricated from black butyl rubber, which contains elemental surfur. Some of the caps were also discolored by a yellowish film.
D7-70-01	MECHANICAL DAMAGE Incorrect part dimensions	Individual pin barrier seal not properly seated when periphery seal compressed.	Molded barriers of pin insert were not dimensioned in accordance with specification requirements.
MSFC-68-3A	MECHANICAL DAMAGE Incorrect part dimensions	Cavity retention device was damaged during rework.	Insertion-bullet-shank length portion of the contact was not per specification. Insertion of the socket would cause damage to the socket cavity retention device.
KSC-67-62	MECHANICAL DAMAGE Chemical attack	The silicone insert was damaged when cleaned by immersion in Freon-TF.	Many hydrocarbon cleaning agents, such as Freon, trichloroethylene, will damage virtually all rubber-like compounds when in contact with the elastomer for any appreciable length of time.
E1-70-01	MECHANICAL DAMAGE Inadequate design	The rear threaded part of the connector turned out of the shell during rework and caused damage to the sealing grommet.	A slight rotary motion on the rear thread part applied a rotary motion on the grommet/hard-insert bond and distorted the sealing cavities in the grommet.
E9-69-07	MECHANICAL DAMAGE Process out of control	Connectors broke during cable manufacture.	Shell insert retention grooves had been machined to wrong dimension which resulted in localized thinning of the shell wall.
G4-A-72-01	MECHANICAL DAMAGE Process out of control	Excessive bonding material spillover into connector cavity from insulator sandwich bonding operation, and excessive misalignment of sandwiched insulators	Condition prevented contacts from properly seating with normal insertion forces.

RF CONNECTORS

ALERT NO.[1] (GIDEP)	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
D7-A-72-08	OPEN Incorrect part used	Contacts would not intermate.	The crimp version and solder version contacts for the same connector body will not intermate.
K9-71-06	OPEN Contamination	Connectors showed a high insertion loss.	Failure analysis revealed some devices were dimensionally out of specification and others contained metallic particles on the recessed Teflon surface.
E9-A-72-01	OPEN Contamination	Box level continuity problems were isolated to a connector.	Failure analysis revealed that the screw threads of the contact interconnect had Locktite coating which formed an insulating film between the threads.
C6-71-03	OPEN Process out of control	Receptacle separated at the brazed body joint following test.	Microscopic examination of the failed joint revealed that the silver solder preform had not been heated sufficiently to melt the solder. Analysis also revealed defective center conductor threads and Locktite contamination.
G4-70-01	SHORT Incorrect part dimensions	Center conductor of coaxial cable shorted to connector shell.	Improper seating of center pin contact results in short circuit failure of the mating coaxial cable. This condition causes the center socket of the mating plug connector to be forced back, buckling the center conductor of the coaxial cable and shorting to the shell of the connector.
MSC-A-72-01	ELECTRICAL PARAMETER DEVIATION - EXCESSIVE RF LEAKAGE Inadequate design	Connectors exhibited excessive RF leakage. Isolation was -60 dB at 2 to 3 MHz, should be -90 dB minimum.	Analysis revealed that the shield was not in positive contact. Addition of a swage washer provided positive metal-to-metal contact by clamping the braid from the outside.
LaRC 3-2-67	MECHANICAL DAMAGE Inadequate design	Pin entered between socket and insert and split insert.	The connector construction allowed the end of the pin to be displaced from the center line by weight of the coaxial cable or some other similar force. Since there is no provision for guiding the pin into the socket, entry of the pin between the socket and insert results.
L1-69-01	MECHANICAL DAMAGE Process out of control	Coupling nuts came off of connector when subjected to pull test.	Inadequate swaging of coupling nuts resulted in about 8 percent of them coming off of the connectors. Other mechanical defects indicated inadequate machining and inspection control.
C6-70-04	MECHANICAL DAMAGE Incorrect part dimensions	The coupling nut of the coaxial plug separated from the connector body.	The rear faces of the retaining ring groove were machined improperly with a sloped instead of a square face.

MISCELLANEOUS CONNECTORS

TYPE; ALERT NO.[1] (GIDEP)	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
ADAPTER KSC-70-13	ELECTRICAL PARAMETER DEVIATION - POLARITY REVERSAL Specification error	Signal though the adapter reversed polarity	Adapter had wrong key configuration because of error in MIL-C-3655/4 (ref 12).
HUBBELL GSFC-70-10, 10A	MECHANICAL DAMAGE Installation methods	Connector overheated, arced, and caused a minor fire.	The connector was improperly installed. Copper tips (supplied by the manufacturer) for the stranded wires in the cable to which the connector was attached were not used.
JACK KSC-71-01	OPEN Process out of control	Intermittent failure of normal-through contacts to make continuity.	Analysis showed some jacks had cross-pin contactor not centered in plunger mechanism, while some had a larger or stronger spring which binds in the barrel and prevents the plunger's return to normal contact position. Contact resistance varied from 20 milliohms to infinity.
RECT KSC 11-17-66	OPEN Process out of control	Open circuits were observed in electrical terminal distributors.	Weld failures in a female-to-female contact, intended to connect two patching wires to a single pin, resulted in loss of continuity.
RECT KSC-69-19	OPEN Contamination	Flow of solder flux or potting compounds in nonhermetic connectors can cause increased contact resistance or intermittents.	Laboratory analysis revealed that the contacts of nonhermetically sealed connectors may become contaminated by solder flux or potting compounds. Solder flux is difficult to detect visually as it is extremely thin and transparent. However, after the contacts have been engaged and disengaged, the normal rubbing action will transform the flux into an opaque, whitish deposit.
RECT KSC-71-04	SHORT Contamination	Connectors demonstrated intermittent shorts between pins	Investigation revealed shorts were caused by corrosion or contaminant particles forming a bridge between pins. Cause of the problem believed to be a flow of air (with traces of hydrogen sulfide and moisture) over the unprotected base of the connectors.
RECT GSFC 69-12, 12A	MECHANICAL PARAMETER DEVIATION - LOW RETENTION FORCE Vendor testing	Socket contacts failed a contact separation test during test prior to fabrication	Investigation revealed that the crimp which secures the contact sleeve to the contact had failed, allowing the sleeve to slide toward the rear of the contact. This condition was caused by excessive force applied to the contact sleeve during a retention test performed by the vendor.

MISCELLANEOUS CONNECTORS

TYPE; ALERT NO.[1] (GIDEP)	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
RECT GSFC-70-05	MECHANICAL PARAMETER DEVIATION EXCESSIVE MATING FORCE Process out of control	During assembly by user, abnormally high mating forces and contact insertion forces were observed	Defective processing, including misalignment of socket insert components and inclusion of out-of-round retention clips, resulted in abnormally high force requirements for insertion of contacts and mating.
RECT MSFC 7-12-67	MECHANICAL DAMAGE Bent and cracked components	During mechanical inspection, cracked and bent components were observed.	A commercial part produced without any special test or inspection requirement.
RECT E9-68-06	MECHANICAL DAMAGE Process out of control	Broken female contact found during acceptance testing of cable assembly	Fracture occurred at necked-down center area of crimp barrel. Depth of hole exceeded tolerance and penetrated into solid part of shank.
RECT X1-71-01	MECHANICAL DAMAGE Process out of control	Subminiature plugs and receptacles failed during torquing operations.	The female jacking hardware and the female sockets contacts fractured because the holes had been drilled too deep in both the jacket socket and socket contact. This action resulted in a very thin wall of material being left.
RECT KSC-71-03, 03A	MECHANICAL DAMAGE Broken leads	Transistor socket leads were broken when mounting the sockets in a printed wiring board hole.	Leads were forced to bend, decreasing their bend radius, because the printed wiring board did not contain relief slots.
PRINTED CIRCUIT BOARD Y1-72-01	OPEN Defective component	Loss of signal was experienced at the connector/card interface during chassis check-out.	Examination of connectors revealed: (1) cracks along back, (2) bowing of connector body, (3) decrease in contact pressure of center contacts, and (4) movement of contact element out of contact with the board. Failure analysis by the manufacturer disclosed cracking of the insulator body during use caused by internal stress cracks which occurred during manufacture.

NOTE:
1. Where no ALERT number (GIDEP) exists, the originator and date are shown.

SECTION 5
FASTENERS
(GIDEP CODE 307)

5

CONTENTS

INTRODUCTION

Objective. The objective of this section is to identify the major problem areas associated with the use of fasteners and to provide approaches (developed from experience) for dealing with those problems.

General. Fasteners, as opposed to other attaching methods such as soldering, brazing, bonding, etc. described elsewhere in this publication, are permanent or removable attachments. Although fasteners can be fabricated from phenolics and other plastic materials, the majority are constructed from metals, with an emphasis on the higher strength alloys such as A-286 CRES, for self-evident structural reasons.

Mechanical Fastening Systems. These may be divided into two general classifications:

1. Permanent: such as rivets, lockbolts, etc., which normally require the destruction of a part to disassemble (obviously not for routine maintenance).

2. Removable: consisting of threaded components, for which removal is accomplished during routine maintenance without destruction of any part.

Problem Description. The problems are first defined by use of specific examples cited in ALERT reports, and then by using the broader base of information available from other industry and government investigations.

Problem Prevention. Problem prevention is dealt with by providing relevant information with respect to tooling, design factors, and inspection criteria as applicable.

PROBLEM AREA/CAUSE AND SUGGESTED ACTION

Problem areas and causes associated with Fasteners are shown below. Suggested actions fcr minimizing the problems are indicated as applicable. The "ALERT ITEM NO." relates each entry to the summaries of ALERT reports which are presented in the last portion of the Fastener Section.

FASTENERS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
NUT FRACTURE Process control	1	Adequate inspection at time of receipt, including metallurgical examination as required. Manufacturer institute adequate QC procedures.
BOLT HEAD FAILURE Process control	2	
SCREW SEIZURE Process control	3	
NUT SUPPORT BRACKET FAILURE Process control	4	
NUT CRACKED Hydrogen embrittlement	5	Adequate inspection at time of receipt, including metallurgical examination. Testing for hydrogen embrittlement should be specified in the procurement document.
NUT FAILURE Stress corrosion/hydrogen embrittlement	6	Control use and location of materials that accelerate corrosion of structural members subject to mechanical stressing.
CRACKED STUDS Faulty material	7	Specify correct material on the procurement document. Manufacturer institute adequate QC procedures. Metallurgical inspection at time of receipt
BROKEN SCREW Improper material	8	
BOLT HEAD FAILURE Stress corrosion	9	Limit use of stress-corrosion sensitive materials for fabrication of structural attachments.
IMPROPER LUBRICANT Incompatibility of materials	10	Do not use cetyl alcohol lubricated or green dye coded fasteners in LOX atmosphere.
CRACKED LOCKWASHERS Hydrogen embrittlement	11	Cadmium plated steel parts should be tested on a lot basis to insure that parts meet the required physical properties. Testing for hydrogen embrittlement should be specified in the procurement document.

THREADED FASTENERS

REMOVABLE (THREADED) FASTENING SYSTEMS

General. The following discussion will center on the removable type of threaded fasteners, with particular attention to the medium-to-high strength alloys, such as A-286 CRES and 6AL-4V titanium. While the majority of fasteners being used are of the permanent type, the problems associated with removable fasteners receive the most attention.

Removable Fasteners. This classification includes bolts, studs, nuts, platenuts, inserts, tapped holes, along with a large array of retained panel and other special fastening systems. Torque is applied either to the bolt head or the nut element through such external drive configurations as the hexagon, 12-point, or spline; and through such bolt head internal recesses as the Torq-Set, Hi-Torque, Phillips, Tri-Wing, square, and hexagon shapes.

Locking Methods. The mechanical or frictional locking element of the threaded fastening system is designed to prevent separation under vibration. This locking effect is achieved in the bolt by the use of plastic (nylon, vespel) inserts, by controlled thread deformation, or by providing drilled holes for safetying in either bolt head or the threaded end. Similarly, the nut element may have plastic inserts, crimped or deformed threads, or have castellated provisions for safetying. Another separate part, the lock washer, is a less desirable device. In aerospace applications, its use should be avoided if the contamination (metallic/finish particulate matter) generated by it can affect electronic circuitry or interfere with optical equipment. In other fields, factors such as the cost of stocking and handling a separate component and the potential loss of the lock washer upon routine disassembly should be considered.

ALERT Problems. Some of the ALERT reports summarized herein are problems representing various facets of inadequate quality control practices. Others reflect the fact that the designer failed to consider all environmental factors as well as the strength requirements affecting his selection of a fastening system.

Galled/Stripped Threads. A major problem area in threaded fastening systems is the galled or stripped thread. This failure mode is potentially present whenever a locking element is required or if the improper thread lubrication is used. Other factors could be oversize or undersize threads or incompatible materials. The usual indicator is excessive torque on installation or removal.

Choosing a System. It is suggested that the designer choosing a fastening system use care to see that the combination of nut and bolt delivers the locking force desired, free of excessive torque. Normally the requirement of compliance with MIL-N-25027 (ref 13) is specified. A simple bench test of the actual parts can verify performance. In addition, the smoking and outgassing of the materials involved should be considered if applicable to the design. On critical applications, consideration should be given to assuring adequate identification of system components.

Excessive Torque. Excessive torque leads to the consideration of another problem — the "cammed out" internal wrenching recess in the bolt head. This occurs when the driving tool damages the recess as torque is applied. This results in having to drill out and replace the damaged bolt. The solution lies in the selection of the proper recess, or external wrenching bolt head configuration (and tool) and, as above, matching the nut "crimping" to the bolt material.

Vibration/Fatigue. Vibration and fatigue can be of major concern to the designer in the selection of the proper threaded fastening system. Fatigue characteristics of high strength materials (160-180 ksi and above) have been improved in recent years by the application of rolling techniques to the forming of the thread configuration as in MIL-S-8879 (ref 14) and to the head-to-shank fillet. This is particularly true in the A-286 CRES material in the higher strength ranges. Recent innovations in thread design, i.e., the thread angle and lead control, have resulted in a better load distribution. Extensive testing has demonstrated an increase in fatigue life on the order of 20 percent.

RECESS SYSTEMS

DISCUSSION

Definition. A recess is defined as a manufactured groove, slot, or depression in the heads of bolts and screws through which torque is applied by use of a driver. A recess system implies a parallel, controlled description of the matching series of driver configurations.

General. The history of recesses is similar to the mousetrap. Many shapes have been developed over the years with both desirable and undesirable features. As a result, a designer should avoid the use of several recess types in his designs because of the cost aspect, not only for the stocking of parts, but for the various tools required and the repair work generated by the possible use of the wrong driver. Each succeeding recess design attempts to present a unique feature. Inherent in this approach is that the recess design attempts to prevent misuse of earlier types of driver.

Trade-offs. A recess is a series of design compromises. Too deep a recess weakens the head-to-shank strength. Too shallow a recess results in lowered torque transfer capability. "Camout" can occur when the flank face of internal wrenching element slopes too much or is too close to the center of the recess.

Recess Requirements. The following factors should be considered in the selection of a recess:

1. The torque required to be transmitted.

2. The internal wrenching element. This torque transfer surface should be situated along a radial line and extend as far as possible away from the recess center. This surface area should be consistent with the torque requirements and the strength of the bolt material. The surface should be perpendicular or have a reverse slope to reduce axial loading of the driver.

3. The bolt head shape. The type best suited for a recess is the flat fillister protruding head or the 100-degree flush head. These configurations provide maximum wrenching surfaces at the outer extremities of the recess.

4. Recess forming method. The recesses are generally formed in the bolt heading process or machined afterwards. The formed or forged recess is better from the strength standpoint but does not necessarily provide the best recess design.

PRESENT RECESS SYSTEMS (MAJOR TYPES)

1. Phillips; Reed & Prince. These recesses are similar - both are cross shaped. The Reed and Prince has narrow walled legs; the Phillips legs are wider and the center is opened to provide for a stronger shanked driver. Both of these recesses are classed as low torque drive.

2. Internal Sockets (Square, Hexagon, Spline). As the name implies, the recess openings are four or six sided or, in the case of the spline, provided with 10 radially aligned, vertical, torque transfer elements.

3. Pozi-Drive. This is the basic Phillips recess changed by adding another cross at 45-degrees to the main drive. The purpose of these narrow, pointed recess legs is to seat the driver more firmly.

4. Hi-Torque. This curved-bottom, slot-like recess is machined so as to provide a reverse slope to the torque transfer surface. This provides for tool retention in the recess under torque load.

5. Torq-Set; Tri-Wing. These recesses are similar in design. The Torq-Set four and the Tri-Wing three wing surfaces are offset so that the insertion torque is transferred along a radial line for maximum efficiency.

6. Multi-Torque. This recess is formed by machining two narrow parallel keyways or slots in the bolt head.

7. Clutch. This recess is similar in appearance to the Hi-Torque except that groove is wider and there is no reverse slope to the wrenching elements.

8. Six-Cess. This recess resembles the internal spline socket with the exception that the center opening for the driver shank is smaller in diameter.

TORQUE VALUES FOR BOLTS

BOLT SIZE	LOW CARBON STEEL	18-8 CRES	BRASS	SILICON BRONZE	ALUMINUM 24ST-4	316 CRES	MONEL
	IN-LB	IN-LB	IN-LB	IN-LB	IN-LB	IN-LB	IN-LB
2-56	2.2	2.5	2.0	2.3	1.4	2.6	2.5
2-64	2.7	3.0	2.5	2.8	1.7	3.2	3.1
3-48	3.5	3.9	3.2	3.6	2.1	4.0	4.0
3-56	4.0	4.4	3.6	4.1	2.4	4.6	4.5
4-40	4.7	5.2	4.3	4.8	2.9	5.5	5.3
4-48	5.9	6.6	5.4	6.1	3.6	6.9	6.7
5-40	6.9	7.7	6.3	7.1	4.2	8.1	7.8
5-44	8.5	9.4	7.7	8.7	5.1	9.8	9.6
6-32	8.7	9.6	7.9	8.9	5.3	10.1	9.8
6-40	10.9	12.1	9.9	11.2	6.6	12.7	12.3
8-32	17.8	19.8	16.2	18.4	10.8	20.7	20.2
8-36	19.8	22.0	18.0	20.4	12.0	23.0	22.4
10-24	20.8	22.8	18.6	21.2	13.8	23.8	25.9
10-32	29.7	31.7	25.9	29.3	19.2	33.1	34.9
1/4"-20	65.0	75.2	61.5	68.8	45.6	78.8	85.3
1/4"-28	90.0	94.0	77.0	87.0	57.0	99.0	106.0
5/16"-18	129	132	107	123	80	138	149
5/16"-24	139	142	116	131	86	147	160
3/8"-16	212	236	192	219	143	247	266
3/8"-24	232	259	212	240	157	271	294
7/16"-14	338	376	317	349	228	393	427
7/16"-20	361	400	327	371	242	418	451
1/2"-13	465	517	422	480	313	542	584
1/2"-20	487	541	443	502	328	565	613
9/16"-12	613	682	558	632	413	713	774
9/16"-18	668	752	615	697	456	787	855
5/8"-11	1000	1110	907	1030	715	1160	1330
5/8"-18	1140	1244	1016	1154	798	1301	1482
3/4"-10	1259	1530	1249	1416	980	1582	1832
3/4"-16	1230	1490	1220	1382	958	1558	1790
7/8"-9	1919	2328	1905	2140	1495	2430	2775
7/8"-14	1911	2318	1895	2130	1490	2420	2755
1"-8	2832	3440	2815	3185	2205	3595	4130
1"-14	2562	3110	2545	2885	1995	3250	3730
	FT-LB	FT-LB	FT-LB	FT-LB	FT-LB	FT-LB	FT-LB
1-1/8"-7	340	413	337	383	265	432	499
1-1/8"-12	322	390	318	361	251	408	470
1-1/4"-7	432	523	428	485	336	546	627
1-1/4"-12	396	480	394	447	308	504	575
1-1/2"-6	732	888	727	822	570	930	1064
1-1/2"-12	579	703	575	651	450	732	840

TORQUE VALUES FOR NUTS - INCH-POUNDS

BOLT, STUD, OR SCREW SIZE		ON STANDARD BOLTS, STUDS AND SCREWS HAVING A TENSILE STRENGTH OF 125,000-140,000 PSI		ON BOLTS, STUDS, AND SCREWS HAVING A TENSILE STRENGTH OF 140,000-160,000 PSI	ON HIGH STRENGTH BOLTS, STUDS AND SCREWS HAVING A TENSILE STRENGTH OF 160,000 PSI AND OVER
Coarse Thread	Fine Thread	Shear-type Nuts (AN320, AN364, or Equivalent)	Tension-type Nuts and Threaded Machine Parts (AN310, AN365, NAS679A, NAS1291 C, MS21043 or Equivalent)	Any Nut, Except Shear-type (Used for NAS1291, MS21042)	Any Nut, Except Shear-type (Used for NAS1291, MS21042)
8-32	8-36	7-9	12-15	14-17	15-18
10-24	10-32	12-15	20-25	23-30	25-35
1/4-20		25-30	40-50	45-59	50-68
	1/4-28	30-40	50-70	60-80	70-90
5/16-18		48-55	80-90	85-117	90-144
	5/16-24	60-85	100-140	120-172	140-203
3/8-16		95-110	160-185	173-217	185-248
	3/8-24	95-110	160-190	175-271	190-351
7/16-14		140-155	235-255	245-342	255-428
	7/16-20	270-300	450-500	475-628	500,756
1/2-13		240-290	400-480	440-636	480-792
	1/2-20	290-410	480-690	585-840	690-990
9/16-12		300-420	500-700	600-845	700-990
	9/16-18	480-600	800-1,000	900-1,220	1,000-1,440
5/8-11		420-540	700-900	800-1,125	900-1,350
	5/8-18	660-780	1,100-1,300	1,200-1,730	1,300-2,160
3/4-10		700-950	1,150,1,600	1,380-1,925	1,600-2,250
	3/4-16	1,300-1,500	2,300-2,500	2,400-3,500	2,500-4,500
7/8-9		1,300-1,800	2,200-3,000	2,600-3,570	3,000-4,140
	7/8-14	1,500-1,800	2,500-3,000	2,750-4,650	3,000-6,300
1"-8		2,200-3,000	3,700-5,000	4,350-5,920	5,000-6,840
	1"-14	2,200-3,300	3,700-5,500	4,600-7,250	5,500-9,000
1-1/8-8		3,300-4,000	5,500-6,500	6,000-8,650	6,500-10,800
	1-1/8-12	3,000-4,200	5,000-7,000	6,000-10,250	7,000-13,500
1-1/4-8		4,000-5,000	6,500-8,000	7,250-11,000	8,000-14,000
	1-1/4-12	5,400-6,600	9,000-11,000	10,000-16,750	11,000-22,500

Torque Requirements

Torque values for tightening MS nuts are similar to values specified for AN nuts. The limiting factor for torque limits is the bolt or screw on which the particular nut is utilized. For example, an MS nut having a tensile strength of 160,000 psi could be utilized on an equivalent strength bolt and be torqued accordingly. However, if a 160,000 psi MS nut is used on a bolt having a tensile strength of 140,000 psi, then the torque for the 140,000 psi range would apply. The torque values for AN, NAS, and MS nuts are listed in the above table.

ALERT SUMMARIES

Summaries of ALERT reports issued against Fasteners are shown below. The "ALERT ITEM NO." (first column) refers each ALERT back to the "Problem Area/Cause and Suggested Action" table.

FASTENERS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
1 MSFC-65-01	NUT FRACTURE Process control	Three NAS1022A nuts failed by cracking during fabrication of an aerospace structure.	Minute cracks existed in used as well as unused nuts. These cracks were in the milled slots and were covered by cadmium plating.
2 MSFC-68-05	BOLT HEAD FAILURE Process control	Cap screws, used in aerospace equipment, were found with cracked heads, internal wrenching flats rounded out, and/or heads broken from shanks.	Analysis indicated inadequate manufacturing and heat treating.
3 E9-69-08	SCREW SEIZURE Process control	Panel screws that could not be removed after installation.	Examination revealed oversize threads and pitch diameters, improper heat-treating, cracked recesses, plus a variety of recess sizes.
4 LeRC-67-12	NUT SUPPORT BRACKET FRACTURE Process control	Tensile loading of the bracket causes complete separation of nut from the bracket.	The anchor nuts have forming-cracks that propagate into a network of small grain boundary fractures due to excess heat-treating as evidenced by surface decarburization to a depth of .005 inch. Expansion of the epoxy potting compound during thermal cycling, applies tensile stress to anchor nuts, which results in complete fracture.
5 S3-72-1	NUT CRACKED Hydrogen embrittlement	Nut elements (2 lug floating nut plate) were found cracked after some years of service	Failure analysis results indicated hydrogen embrittlement.
6 MSC 2-7-67	NUT FAILURE Stress corrosion/hydrogen embrittlement	During check-out of an aerospace system, failure of four frangible nuts was discovered	The failure is believed to be initiated by stress corrosion and/or hydrogen embrittlement in a region of high stress resulting in cocked loading of the nut and its washer. Analysis revealed ammonium fluoroborate (NH_4BF_4) on the fractured surface of the nut. Subsequent torquing of good nuts that had been immersed in NH_4BF_4 resulted in fractures occurring in 7 days or less.

FASTENERS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
7 D7-69-04	CRACKED STUDS Faulty material	Used and unused studs exhibited cracks with internal corrosion.	Metallographic examination disclosed that failure was due to intergranular corrosion caused by improper carbide solution treatment. Studs were made from a rod material that was not properly solution heat-treated and water-quenched prior to fabrication. The stainless characteristic of this material (Type 304 stainless) can be destroyed by chromium depletion at the grain boundaries during slow cooling through the sensitization temperature range.
8 B2-71-02	BROKEN SCREW Improper material	Cap screws failed in shear.	Spectrographic analysis indicated the screws were made from an improper material.
9 MSFC-69-3	BOLT HEAD FAILURE Stress corrosion	During rework of aerospace equipment, the head of one flange bolt was partially sheared when torqued to 140 inch-pounds.	Metallurgical analysis revealed stress corrosion as the failure mode, caused by the combined forces of stress and corrosive environment. The bolt, which had been installed for 2-1/2 years, was fabricated from 7075-T6 aluminum alloy, a material that is susceptible to stress corrosion cracking.
10 MSFC-A-72-09	IMPROPER LUBRICANT Incompatibility of materials	Hi-lok fasteners made of A286 alloy cadmium plated used cetyl alcohol lubricant and green dye color coding.	The lubricant and dye are not LOX compatible.
11 D4-A-72-02	CRACKED LOCKWASHERS Hydrogen embrittlement	Lockwashers cracked during torquing of vehicle attach bolts.	Metallurgical evaluation revealed the washers had cracked under strain due to hydrogen embrittlement. The embrittlement resulted from the application of an insufficient post-cadmium plating baking process.

NOTE:
1. Where no ALERT number (GIDEP) exists, the originator and date are shown.

SECTION 6
FUSES/CIRCUIT PROTECTIVE DEVICES
(GIDEP CODE 341)

6

CONTENTS

INTRODUCTION

OBJECTIVE

The objective of this section is to identify the major problem areas associated with the use of fuses/circuit protective devices and to suggest approaches (developed from experience) for dealing with those problems.

SECTION ORGANIZATION

The fuse/circuit protective device section is presented with the following organization:

General

1. Basic failure problems associated with fuses/circuit protective devices are identified based upon ALERT and industry experience.

2. Where applicable, a screening technique is suggested for detecting finished parts having a potential for failure.

Subtopics - Treatment of Specific Types

1. Fuse/circuit protective device type background.

2. For those in the process of selecting parts and manufacturers, or attempting to eliminate part problems at the manufacturer levels, a portion is devoted to describing the inner construction of selected types and describing the manufacturing sequence necessary to produce the part. Particular emphasis is given to the design or manufacturing deficiencies associated with the identified failure mechanisms.

3. Basic approaches are provided to assist in developing a competent failure analysis plan where corrective action at the part level is desired. The material is arranged so that one experiencing a specific problem can identify those steps in the failure analysis process likely to reveal that problem.

Fuse Types. Fuse/circuit protective devices have been divided into subtopics according to their internal construction. This section of the publication includes a detailed discussion of the subminiature hermetically sealed fuse, which is the design most frequently used in aerospace applications. Other subtopics such as circuit breakers, fuseholders, sealed cartridge type fuses, and solid state type fuses are included as summaries of ALERT reports.

FUSE FUNDAMENTALS

What a Fuse Should Do. A fuse is a device that can be used to open an electric circuit when the current flow level exceeds the current carrying versus time rating of the fuse. The fuse must be installed in series with the current flowing in that circuit so that all current to be interrupted flows through the fuse element. Ideally the fuse should carry its rated current without opening the circuit and only open the circuit when its current carrying versus time rating is exceeded. The primary characteristics for fuses are current carrying capacity versus time, maximum current that can be interrupted, and maximum voltage. These primary characteristics are dependent on the physical size and spacing of the current carrying components and the construction materials used.

Practical Considerations. Analysis indicates that because of the physical imperfections in materials and laws that govern their properties, a fuse cannot be simply defined by its current carrying capacity and voltage rating. Physical considerations force us to recognize such compromising characteristics built into the fuse as mechanical stability (sensitivity to vibration caused malfunction), insulation resistance, dielectric withstanding voltage, thermal stability, time required to open circuit, maximum interrupt current, the effect of the media in which the fuse is located on its operation, i.e., liquid, free air, vacuum, ambient temperature, moisture, conformal coating if used (such as epoxy), and others. These characteristics are a composite result of materials and processes used in fabrication, plus mechanical design considerations.

FAILURE MODES

Failure Categories. Part level failure problems associated with the fuses may be lumped under two basic categories: catastrophic opens and catastrophic failures to open. A catastrophic open would be classified as fuse premature opening and interrupting current flow due to mechanical breaking of the fuse element, or any similar type interruption of current other than the fuse element opening within its specified normal opening range due to current flow level. A catastrophic failure to open would be classified as failure to open when current level passing through the fuse exceeds the fuse rating without interruption. This is most commonly due to some electrically conductive material bridging or shorting fuse terminals together parallel to the fuse element. It must be recognized that catastrophic opens and catastrophic failures to open are worst case conditions of certain electrical parameter deviations. Failure analysis must be made at the part level in order to determine the cause of these conditions and proceed to corrective action.

ELIMINATING DEFECTIVES

Problem Solving Approach. The approach taken in this section will be to identify the user encountered problem areas associated with a particular type of fuse, then provide suggestions for eliminating those fuses prone to exhibiting those problems at the finished fuse level, the design level, and at the manufacturing level.

Finished Fuse Level. Recognizing that the typical consumer is faced with using finished devices that are on hand, information is provided for screening - sorting the bad ones from the good. Suggestions are made for subjecting the fuses to environmental stresses (capable of identifying defective units, but well within the safe operating margins for properly made units). This reliability technique has found use not only for sorting, but for providing assurance that the manufacturer has controlled his processes.

Design Level. While screening has proven to be an effective reliability tool, it does not correct the fundamental problems of design compromises and worse yet, design deficiencies. Design deficiencies must be identified and eliminated at the manufacturer's facility.

Manufacturing Level. The most carefully conceived design can be brought to nought if it is manufactured in an environment lacking necessary controls over critical materials and processes, and allowing substandard workmanship. Again, defectives produced as a result of these conditions can be removed using a screening, but since no screen is 100 percent effective, a more desirable technique for removing these potential reliability degraders is to take action to correct these manufacturing conditions by applying controls and providing inspection points.

FAILURE ANALYSIS

Objective. A primary objective of failure analysis is to identify failure mechanisms at a level such that corrective action is feasible. Knowing nothing more about a fuse than that it is open does not allow effective corrective action. If we learn that the open is caused by a weak terminal wire bond, we now have identified a mechanism suitable for corrective action. The bonding of the terminal wire can be strengthened, thereby improving the reliability of the design.

Failure Verification. After recording all identifying markings, and performing a thorough external and radiographic inspection, the first requirement is to verify the failure. Often the fuse is shown to have operated normally by interrupting a current that exceeded the fuse rating.

Analysis Direction. The process of analyzing a failure, performing those steps necessary on a suspect device which will result in the identification of a specific correctable failure mechanism, requires the coordination of a series of specialized skills by one having knowledge of failure mechanisms, device design, and manufacturing techniques; and the experience necessary to organize this combination of skills and knowledge into a practical plan of action.

When to Analyze. Many part failures occur for which no corrective action is planned to be taken. In many cases it is most cost effective to simply scrap the defective part and replace it with one that performs properly. For those cases where it is necessary to have assurance that future failures will not occur, a portion of this section is devoted to describing some of the considerations involved in performing effective failure analysis.

Reliability/Life. It is anticipated that as a result of this series of actions at the part level (screening, analysis of design and manufacturing, and effective failure analysis) that significant improvement in reliability and life will be realized.

PROBLEM/SCREENING SUMMARY

Scope. The ALERT Summaries represent only a small sampling of the total fuse/circuit protective devices usage experience. In order to provide a more comprehensive compilation, experience from a wide variety of sources (including users and suppliers) is presented. This summation is an accumulation of knowledge and experience gained in dealing with fuse failures and in avoiding those failures. It addresses itself to the causes and effects of failure, and shows the suggested preventive actions that will allow identification of fuses having latent or incipient defects.

This summary is aimed toward identifying fuse problem areas and failure causes. Having identified problems, and recognizing that the typical user is concerned with eliminating this problem from a group of fuses on hand, suggestions are made for performing screening. These screening suggestions are based primarily upon industry experience. The problem areas have been grouped under the basic categories of premature open, failure to open, parameter deviation, and mechanical anomaly.

ALERT Item No. Where directly applicable, the "ALERT Item No." of the ALERT report describing a specific cause for a failure is listed against that cause. Thereby, a cross reference is provided between a specific failure cause found in the "ALERT Summaries" and the broader failure experience/avoidance knowledge shown in this presentation.

Contamination (Including Corrosion) Problem. Experience has indicated that a significant contributor to a fuse/circuit protection device failures is presence of contamination, either as particulate matter or corrosion products. Particulate matter is of two types, conductive and nonconductive. The conductive material, fortunately, is generally detectable by proper X-ray screening, and consists of solder balls, metal flashings, etc. This material can result in failure due to parameter deviation, etc.

The nonconductive material is difficult to detect as it is usually material from the body or case. Presence of this material can result in failure to open as well as premature open. As the case or body material for many of the fuses/circuit protective devices is commonly a semifrangible material, dissection can introduce debris of the same type that is causing the problem, thereby causing the investigation results to be of doubtful nature.

PROBLEM AREA/CAUSE AND SUGGESTED ACTION

FUSES

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspection and Tests")
OPEN Corrosion	1,2	None. Application poblem. Fuse should have been sealed and used in moisture proof holder.
OPEN Cracked substrate	3	All screening tests listed. Manufacturer establish transient voltage limits and application instructions with heat sink use during application of heat to terminal leads.
PARAMETER DEVIATION Cracked substrate	4	All screening tests listed. Review of entire assembly and process with increased control, test and visual inspection at critical points.

FUSEHOLDERS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspection and Tests")
SHORT Design deficiency	5	Visual Examination and Functional Test

CIRCUIT BREAKERS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspection and Tests")
OPEN Contamination Latching difficulty Improper positioning of part	 6 6 7	All screening tests listed with emphasis on Visual and Radiographic Inspection.
PARAMETER DEVIATION Undesirable tripping	8	None. Application problem. Circuit breaker not qualified for environment in which it was used.
PARAMETER DEVIATION Inability to latch	9,10	All screening tests listed with emphasis on Visual and Radiographic Inspection.

SCREENING INSPECTIONS AND TESTS

Basic Screening. The screening inspections and tests suggested for fuse/circuit protective devices included in the Problem/Screening Summary are as follows:

1. Temperature Cycling
2. Run-In
3. Seal Test
4. Electrical and Mechanical Characteristics Measurements
5. Visual Examination
6. Radiographic Inspection
7. Dielectric Withstanding Voltage
8. Insulation Resistance
9. Terminal Strength

Objective. The purpose of the screening is to allow detection of parts that: (1) have been improperly processed by the manufacturer, (2) contain contaminants (including films and corrosion), (3) have poor solder or weld connections, or (4) have any other anomalies that could result in a failure under normal operating conditions.

Additional Screening. In cases where specific characteristics are critical in the function of the using equipment; e.g., voltage drop, resistance, terminal strength, etc., such critical parameters should be added to the requirements of these screening tests.

Envelope Removal/Dissection. The basic approach taken here is to subject each of the devices to a test procedure in order to make a one-by-one acceptance that the internal construction materials, processes, etc., from part-to-part, are homogeneous so that the devices can be treated as a uniform lot. If the devices are not produced under similar design criteria and manufacturing controls which permit a homogeneous lot to exist, a single screening procedure may not be the optimum for all units. For this reason, it is frequently desirable to examine the design and construction. This is accomplished, first, by a nondestructive radiographic inspection; and second, by performing a destructive envelope removal or dissection on a limited sample of devices. This procedure is more meaningful if a design/construction baseline has been established as a comparison criterion.

1. TEMPERATURE CYCLING - MIL-STD-202, METHOD 102 (5 cycles) (ref 2)

   General. This environmental exposure will assist in detecting a variety of design and manufacturing deficiencies resulting from materials with incompatible temperature coefficients of expansion, inadequately joined materials, and materials with improper chemical composition.

   Complementary Tests. Seal, Insulation Resistance at high temperature extreme, and Run-In tests will normally detect degradation and catastrophic failures resulting from Temperature Cycling exposure.

2. RUN-IN TEST (CIRCUIT BREAKERS ONLY)

   The Run-In test is normally performed as an adjunct to Temperature Cycling. It consists of actuating the circuit breaker for 100 cycles or more during the final temperature cycle at both high and low temperature extremes. The primary function of this test is to detect thermally induced misalignments caused by thermal mismatch of the materials used in construction and fundamental errors in mechanical design of the device. It is useful, also, to detect incipient defects caused by thermal and/or mechanical fatiguing, such as stress corrosion, on the individual components of the circuit breaker.

3. INSULATION RESISTANCE - MIL-STD-202, METHOD 302, CONDITION B (ref 2)

This test measures the resistance offered by the insulating members of the circuit breaker to an impressed direct voltage tending to produce a leakage current through or on the surface of these members. Low insulation resistance, by permitting the flow of large leakage currents, can disturb the operation of circuits intended to be isolated by forming feedback loops. This test is especially helpful in determining the extent to which insulating properties are affected by deteriorative forces, such as heat, moisture, oxidation, etc. It is normally performed while the circuit breaker is stabilized at high temperature during final cycle of thermal cycling.

Insulation resistance on fuses is measured between fuse terminals after overload blowing of the fuse. It is a lot destruct test performed on a sample lot taken from fuses that have successfully passed all nondestruct screening tests.

4. DIELECTRIC WITHSTANDING VOLTAGE - MIL-STD-202, METHOD 301 (ref 2)

The dielectric withstanding voltage test consists of application of a voltage higher than the rated voltage for a specified time between mutually insulated portions of the fuse/circuit protective device, or between insulated portions and ground. This is used to prove that the device can operate at its rated voltage and withstand momentary overpotentials caused by switching surges and other similar phenomena. It serves to determine whether insulating materials and spacings within the device are adequate. After application of the specified overvoltage, the device is examined for evidence of arcing, flashover, and insulation breakdown.

5. SEAL TEST (HERMETIC DEVICES ONLY) - MIL-STD-202, METHOD 112 (ref 2)

General. The purpose of this test is to verify the integrity of the hermetic seal. Typical failure areas occur where materials are fused, brazed, or soldered to make the final seal. The seal test will detect manufacturing defects, damage resulting from handling, seal failures resulting from mismatched coefficient of expansion of materials, etc., which can result in the intrusion of contaminating atmospheres that result in corrosion and/or contamination.

6. ELECTRICAL AND MECHANICAL CHARACTERISTICS MEASUREMENTS (ELECTRICAL FOR FUSES INCLUDES SAMPLE LOT DESTRUCT TESTING; MECHANICAL CHARACTERISTICS APPLIES TO CIRCUIT BREAKERS ONLY)

These tests are designed to verify that the following fuse/circuit protective device characteristics are within specification requirements: operate and release forces, voltage drop, resistance, and operating position. Because of the variety of designs found in the various kinds of fuse/circuit protective devices, exact methodology for testing will not be defined, except for contact resistance. The test employed for measurement of contact resistance is MIL-STD-202, METHOD 307, and applies to circuit breakers only.

7. VISUAL EXAMINATION

Precap visual examination at the manufacturer's facility is recommended as a screening requirement. During the precap visual, just prior to sealing the body or housing, all internal surfaces of the body or housing and contact surfaces are carefully examined for evidence of any loose particles, film contaminants, or other foreign material. For this examination a 20 power minimum magnification microscope is used.

8. RADIOGRAPHIC INSPECTION

In those cases where loose internal metal particles or misalignment of the components, etc., is a problem, X-ray inspectionn of each fuse/circuit protective device is recommended as a screening requirement after sealing or final assembly operation.

9. TERMINAL STRENGTH (FUSES ONLY)- MIL-STD-202, METHOD 211, TEST CONDITION A (ref 2)

Terminal strength testing includes a five pound axial static pull applied to each terminal separately in turn with the fuse body held stationary. Loose or defective terminals can cause strain to be applied to the fuse element resulting in catastrophic open or loss of hermetic seal resulting in parameter deviation. Normally this test will precede seal testing.

SUBMINIATURE HERMETICALLY SEALED FUSES

CHARACTERISTICS

General Considerations. Fuses are devices that interrupt the flow of current in response to current level stimuli accomplished by the melting of a conductive bridge between two terminals. The melting normally occurs in the midpoint of the element because each end cap lead assembly provides limited heat sinking resulting in a thermal gradient along the length of the element with maximum occurring at midpoint. Due to surface tension considerations the melt back results in semiglobule formation on each end of the separated ends of the element. Degradation of the surfaces of the element or application of excessive transient mechanical forces can degrade or cause false operation of the installed fuse. Not to be overlooked in any discussion of operational limits for fuses are the insidious atmospheric effects such as shift in time to open because of low atmospheric pressure, etc., generally associated with nonhermetic fuses.

Atmospheric Effects. The nonbenign effects of atmospheric environment on nonhermetic fuses can be divided into two broad categories, altitude or vacuum effects, and atmospheric composition effects. At altitudes above 10,000 feet, the reduction of thermal conductivity of air continues until it reaches its minimum in space. Fuses that operate within prescribed limits at sea level are prone to decrease in time current levels in space. Effects on nonhermetic sealed fuses resulting from atmospheric composition include increase in corrosion and/or film deposit on element surfaces caused by presence of moisture or other reactive substances in a gaseous form.

Transient Force Effects. The majority of fuses used in aerospace are the subminiature hermetically sealed type with wire lead terminals. This design is easy to mount on circuit boards with the fuse body held in place by epoxy bonding without any strain on the terminal leads. The epoxy type mounting minimizes the effect of transient mechanical forces (shock and/or vibration) by providing both damping and rigid mounting. This type mounting distributes the externally applied transient mechanical forces evenly over the entire fuse body and tends to eliminate transient forces encountered in service. The epoxy bonding material circuit board, and conformal coating (conformal coating is generally used) tend to absorb and thereby reduce the level of externally applied transient mechanical forces transmitted to the fuse.

Temperature Effects. The heat generated by the resistance to current flow in the fuse element bridging the fuse terminals provides temperature rise with current increase until the melting temperature of the fuse element is reached causing the element to open and interrupt the flow of current. The time required for the fuse element to open is a function of current level of flow through the fuse, fuse element resistance, fuse element melting temperature, ambient temperature, and thermal conduction of the media surrounding the fuse body. Generally the fuse current rating and time to open, versus current level, are established in free air at a temperature of 25°C. For low temperature extremes of -55°C the rating is increased 10 percent, and decreased 10 percent for high temperature extremes of 125°C. Locating the fuse body in a surrounding media with more or less thermal conductivity than free air will increase or decrease respectively the time to open slightly; however, this effect is minimized to some extent in hermetically sealed fuses. Heat applied to the fuse terminals during tinning and soldering processes can damage the fuse, therefore, heat sinks should be provided.

Current Application Effects. The current applied to a fuse during all testing prior to end item use should be rigidly controlled to the current rating level of the fuse. The fuse should not be subjected to current levels equal to the current rating for any single period of continuous current flow exceeding five minutes and sufficient time must be allowed between these applications of current for the fuse element temperature to stabilize at ambient temperature. As a safety factor a period of 24 hours between each five minute continuous rated current application is recommended. Failure to observe this rule may reduce the life and degrade the fuse reliability. These fuses generally are designed and have been qualification tested to carry rated current for a minimum period of four hours. Normally the measurement of voltage drop across the fuse requires that rated current flow through the fuse element for continuous periods of five minutes maximum. Generally the voltage drop is measured after a rated current flow period of one to five minutes during which the fuse element temperature, resistance, and voltage drop have stabilized. For all other testing, such as measuring fuse resistance, the level of current flow through the fuse should be less than 10 percent of the rated current of the fuse.

Installation. Application of strain or pull on the fuse terminal where it is fastened to the fuse body must be avoided. Strength of terminals is a prime consideration and fuses are usually 100 percent screen tested by a 5 pound axial pull on each terminal. Fuses that have overstress or excessive heat applied to the leads prior to, or during, installation may (1) open prematurely causing an open type catastrophic failure, or (2) fail to open if excessive heat remelts internal solder and forms internal solder bridge between terminals.

Specification Parameters. The foregoing discussion has served to delineate application limits of fuses because of physical characteristics associated with their design and materials of construction. These limitations can be described as specification limits for use by manufacturers and using designers. Deviations from these limits can lead to failures.

SUBMINIATURE HERMETICALLY SEALED FUSES

DESIGN AND PRODUCTION CONSIDERATIONS

Failures Related to Process. A typical subminiature hermetically sealed fuse (Figure 6-1) and a typical assembly flow (Figure 6-2) are presented together with the suggested controls required to assure a reliable product. The "Critical Process" is defined for each of the manufacturing steps. Relationship is established between failure causes and the manufacturing process. Having experienced a specific problem, one could identify those manufacturing steps with potential for contributing to the failure.

Assembly Flow. The assembly flow diagram is presented to give an insight into the construction method used in fabrication of a typical subminiature hermetically sealed fuse. The processes and control thereof will vary with each different manufacturer. This flow has been included in order that the user may gain an insight into the types of problems associated with manufacture of the devices. Significant variables are listed on this flow diagram with those operations that are considered critical for the design of a reliable fuse. In addition, the operations have been indexed to the problem area code which will be found on the foldout in the Appendix.

TYPICAL SUBMINIATURE HERMETICALLY SEALED FUSE DESIGN (Figure 6-1)

ITEM	ITEM NAME	MATERIAL OF CONSTRUCTION
1	Outer Sleeve	Plastic tubing per AMS 3632
2	Body	Ceramic, Grade L3B per MIL-I-10 (ref 15)
3	Fuse Element	Depends upon current rating. Typical: nickel, 50/50 copper/silver, 99.90% copper
4	End Cap	9010 brass alloy per MIL-C-21768 (ref 16)
5	Lead	Soft copper per QQ-W-343
6	Solder	98.00% tin, 2.00% silver

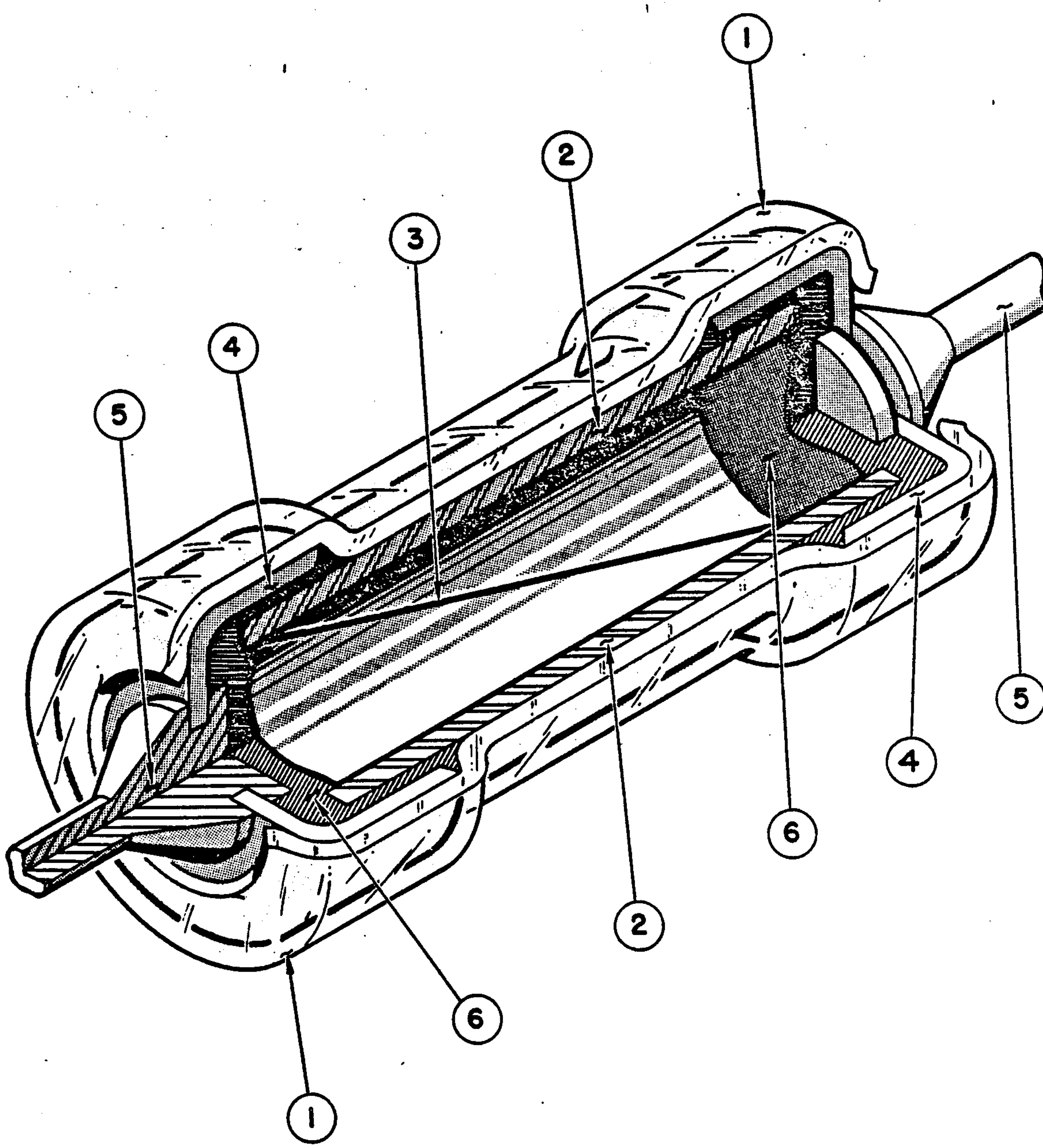

Figure 6-1. Typical Subminiature Hermetically Sealed Fuse

FLOW DIAGRAM			RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL	MANUFACTURING OPERATION	CRITICAL PROCESS	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
End Cap Lead Assembly (4) (5)	Visual Examination	Lead end cap weld and gold plating finish	C, D	D	A2, 3	A, E
Solder Pellet (6)	Mount in fixture and place pellet in cap					
Element Wire (3)						
Ceramic Cylinder (2)	Install element wire in ceramic and insert ceramic cylinder in end cap and solder					
	Remove assembly from fixture and visual examine for end cap and ceramic alignment. Verify element in place.	Alignment and firm seating of ceramic, and good solder bonding of element and ceramic to end cap	C, D, E	A, D, E	A2, 3	
End Cap Lead Assembly (4) (5)	Visual examination	Lead end cap weld and gold plating finish	C, D	D	A2, 3	A, E
Solder Pellet (6)	Mount in fixture and place pellet in cap					
	Insert open end of ceramic cylinder in end cap and solder					
	Remove assembly from fixture and visual inspect for end cap alignment. Hand pull each lead to check solder bond	Ceramic firm seating and solder bonded	C	D	A3	B
	Trim excess element at each end cap					
	QC inspect 3 X minimum visual magnification	Excess element 1/64 inch maximum		E		
	Apply marking, current rating, etc.					
Outer Sleeve (1)	Install sleeve and place assembly on fixture. Bake in oven 345° to 355° F 10 minutes					G
	Pass through gauge 100% for diameter and alignment check					B

Figure 6-2. Subminiature Hermetically Sealed Fuse - Typical Assembly Flow with Related Problem Codes

FLOW DIAGRAM			RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL	MANUFACTURING OPERATION	CRITICAL PROCESS	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
	100% QC inspect 3 X minimum visual magnification for sleeve centered and aligned around each end cap and all marking legible and correct	Sleeve supports end cap and terminal bond and provides hermetic seal	B, C		A1, 3	A, B, E, F, G
	Functional testing, 100% screening, and sample lot destruct test	Eliminates defective units assures homegeneity			A	
Screening and Lot Destruct Test Data Maintained on File by Lot Date Code for Reference as Required	All units except destruct sample cleaned with trichloroethylene and air dried	Removal of external contaminants				J
	All units packaged for shipment					

Figure 6-2. Subminiature Hermetically Sealed Fuse - Typical Assembly Flow with Related Problem Codes

SUBMINIATURE HERMETICALLY SEALED FUSES

FAILURE ANALYSIS TECHNIQUES

General. Failure analysis is a corrective action related procedure. Only after knowing why a part failed can action be taken to minimize future failures. Failure analysis findings can show the need for redesign (improvements in materials, processes and controls) or proper part application.

Predominant Failures. Failures of subminiature fuses can result from problems associated with contamination, mechanical separation, or loose particles.

Case Opening or Delidding. As previously described in the Problem/Screening Summary, detection of native particulate contamination; i.e., contamination that existed prior to failure analysis, is of primary significance in establishing the actual cause of fuse failure. Extreme care should be exercised in case removal so that mechanical separation of element at area of break, internal bridging, or other cause of failure, remains as is and presence of debris generated by the act of delidding is identifiable and thereby does not lead the analyst to false conclusions as to the cause of failure.

Pre-Analysis Investigation. For accurate failure analysis knowledge of actual conditions at time of failure occurrence, detailed factual history of operation and environment the fuse was subjected to is required. This information must be reviewed carefully in those cases where analysis shows the fuse failure verified. In many fuse failure investigations the fuse element is shown to have opened normally as designed and in those cases the cause of the high current level that opened the fuse element must be looked for in the using assembly, or in other external sources. Radiographic inspection can detect if the fuse operated normally.

Failure Analysis Flow. The failure analysis flow (Figure 6-3) provides for maximum nondestructive evaluation of the failed part prior to the dissecting operation.

Relationship to Failures. Where it is relevant, each step of the failure analysis procedure (Figure 6-3) is related to one of the four major problem areas and their causes by a coding system which is defined on the foldout in the Appendix. Thus, one experiencing a specific type of failure can identify those steps in the failure analysis most likely to reveal the problem.

TEST/EXAMINATION	PROCEDURE	WHEN FAILURE IS / LOOK FOR	RELATED PROBLEM CODES (see foldout in the Appendix)			
			OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
NONDESTRUCTIVE MECHANICAL						
External Visual Examination	Note all identifying markings and damage		C, D			all
Radiographic Inspection	If fixed focus X-ray is used, photograph in two or more orthogonal planes as required to record any anomalies within the device. If Vidicon (imaging) is used, examine and photograph anomalies as observed.		B, C	A, B, C, D, E	A1, 2, 3	
PROBLEM AREA VERIFICATION						
NONDESTRUCTIVE ELECTRICAL	Measure and record electrical characteristics, as appropriate, such as Dielectric Withstanding Voltage, DC Resistance, Voltage Drop, etc.		B, C, D, E	A, D, E	A1, 2, 3	
Seal Test (hermetics only)	Fine and Gross Leak Test		C, D		A2, 4	E, F, G, H
INDUCING FAILURES						
Special Conditioning	Baking, Temperature Cycling, and Vibration only if required to confirm problem area					
Electrical Measurements	Repeat appropriate electrical characteristics testing and record changes					
PROBLEM CAUSE VERIFICATION						
Delidding	Remove case (carefully). Observe and record any anomalous conditions such as corrosion, particulate and film contamination, evidence of broken element or loose terminals		B, C, D, E	A, D, E	A1, 2, 3	
Material Analysis Spectrographic Microprobe	Analyze all foreign materials not otherwise identifiable		D, E	A, E	A2, 3, 4	

Figure 6-3. Subminiature Hermetically Sealed Fuse - Typical Failure Analysis Flow with Related Problem Codes

ALERT SUMMARIES

Summaries of ALERT reports against Fuses, Fuseholders, and Circuit Breakers are shown below.

FUSES

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
1 KSC-68-13	OPEN Corrosion	Approximately 15 to 20 percent of a batch of 1,000 fuses tested open although visually they appeared to be good.	Failure analysis revealed a separation of the fuse wire from the soldered end cap. Chemical analysis of corroded wire tips showed the presence of chlorides, indicating the presence of flux. Since the fuses are not hermetically sealed, the flux had combined with moisture to cause the corrosion and eventual open.
2 KSC 72-04, 04A	OPEN Corrosion	Intermittent indicator light problem revealed an open fuse.	Failure analysis determined that the fuse element had failed due to corrosion.
3 ARC 12-22-65	OPEN Cracked substrate	Random occurrence of failures due to opens.	Failure analysis revealed failures were due to cracked substrates caused by uneven heating during soldering. Short leads (3/16 inch) coupled with not using thermal shunts, caused the uneven heating.
4 K4-70-02	PARAMETER DEVIATION Cracked substrate	Fuses were found to contain cracks or fissures in the substrate material. These conchoidal fractures affected their physical property (i.e., resistance, time to clear).	Most of the defects noted were found to occur during the manufacturing cycle prior to encapsulation.

FUSEHOLDERS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
5 R8-70-01	SHORT Design deficiency	Fuseholder would allow circuit continuity even though fuse was blown.	Cause was a change in molding techniques and mechanical configuration internal to the fuseholder. Malfunctioning holders showed a 3-fluted interior surface and flat contact surface on the base terminal. Triple fluted surface allowed the bottom ferrule of the fuseholder to move laterally when pressure was exerted on the base terminal, and short circuit against the middle terminal's soldered connection.

CIRCUIT BREAKERS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
6 K4-69-04	1. OPEN Contamination - plastic chips between contacts 2. LATCHING DIFFICULTY Loose plunger guide	Failure modes experienced were: (1) open circuit when latched, (2) difficulty in latching, and (3) inability to latch.	Cause was chipping of the plunger assembly with the following results: (1) attempt to close the circuit breaker with a chip between the contacts resulted in a bent contact arm and a permanent open condition, and (2) chips and/or a loose plunger guide resulted in various latching difficulties. Chipping is caused by mechanical interference from a defective plunger assembly. Shock and tensile testing on the plunger assembly level has duplicated the breakage as to location and nature of breakage.
7 D7-A-72-10	OPEN Improper positioning of parts	Circuit breakers failed open during testing at 150 percent of rated current.	Investigation revealed that the armature tailpiece failed to engage the lock drive link. The failures were attributed to improper positioning of the armature tailpiece, the frame, and the lock drive link relative to one another.
8 KSC-68-08, 08A	PARAMETER DEVIATION Undesirable tripping	Circuit breakers tripped during a launch and cut off power to monitors.	A testing program on the subject circuit breakers indicates they can be used in all areas subject to the following condition: When used in high vibration areas the circuit breakers should be: (1) rigidly mounted to prevent amplification of vibration effects, (2) pinned to increase resistance to vibration and shock, and (3) exercised previous to any periods of vibration to guarantee that the mechanical trigger is in the full-on position.

CIRCUIT BREAKERS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
9 D7-A-72-11	PARAMETER DEVIATION Inability to latch	Circuit breaker would not hold in the closed position.	Failure analysis revealed a broken handle crank assembly. Visual examination, 40X magnification, of 15 installed handle crack (polyphenelene) assemblies disclosed 5 with fractures at the point of rivet attachment to the catch. The stress oriented fractures had resulted from incorrect (off center) upset of the rivet.
10 MSC-72-05	PARAMETER DEVIATION Inability to latch	Circuit breaker failed to latch.	The malfunction was attributed to bent pivot rivets, internal tolerance build-up, and case shrinkage, which allowed the plunger to bottom out prior to latching.

NOTE:
1. Where no ALERT number (GIDEP) exists, the originator and date are shown.

SECTION 7
GASKETS/SEALS
(GIDEP CODE 345)

7

CONTENTS

INTRODUCTION

Objective. The objective of this section is to identify the major problem areas associated with the use of fluid sealing devices and to suggest approaches (developed from experience) for dealing with those problems.

Problem Definitions. As the existing ALERT reports contain only three failure modes that are directly applicable to fluid seals, the problems are defined from the broad base of information available from industry and government investigations. This section will be limited to the more commonly used fluid sealing devices — gaskets and flanges, dynamic and static seals, as well as gasket seal materials.

Problem Prevention. Problem prevention is dealt with by providing information, with respect to known procedures, to reduce failures that can be attributed to the major problem areas — installation, application, basic design, and original component fabrication.

GENERAL FLUID SEALING DEVICES

General. Fluid seals are devices used to effect separation of gaseous or liquid environments at points of structural transition and at movable component interfaces. Seals used in applications where the involved surfaces do not have relative motion are commonly called gaskets. An example of a structural transition seal is the gasket used in the internal combustion engine between the cylinder head and the basic engine block. This seal completes separation between three distinctly separate environments - ambient air, cooling fluid, and combustible gases. An example of a seal for a movable component interface is the gland seal around the shaft of a rotary pump, separating the fluid being pumped from the ambient surroundings. This type of seal is commonly known as a dynamic seal, and is used to effectively separate the various environments at movable interfaces where there may be reciprocating longitudinal movement as well as rotary motion.

Leakage Types. The most common type of failure for fluid sealing devices is leakage, classified into three basic types: (1) permeation, (2) molecular, and (3) viscous flow. Permeation, as the name implies, is a capillary flow directly through the material. This is primarily because of the degree of porosity of the batch material from which the seal was fabricated. Molecular flow is a similar phenomenon, but it occurs at the interface surfaces and is caused by a finite unoccupied space between the two surfaces of the interface. Molecular flow is proportional to the pressure differential between the separated environments. Viscous flow also occurs on the interface surfaces and is encountered when the minimum cross-sectional area of the leak path becomes large in comparison to the mean free path requirement for gas flow. Viscous flow leakage rate is proportional to the difference between the square of the internal pressure and the square of the external pressure.

Other Failure Mechanisms. In addition to leakage (limited loss of contained fluid), fluid sealing devices fail by rupture because of inadequate back-up rings and excessive pressures, and the introduction of corrosion products or other contaminants. Rupture may be caused by excessive pressure differentials applied to the sealing device, or by shearing mechanical forces applied in an unforeseen rotational mode or as an excessive transverse force. Corrosion products and other contaminants may be caused by normally anticipated environmental considerations, or they may be the result of galvanic corrosion and/or contaminants in inadequately filtered fluid. Because of differences in construction and application between gaskets and dynamic seals, more specific failure mechanism information is found on the following pages.

GASKETS/FLANGES

What is a Good Gasket Seal. Gasket seals consist of three basic elements: (1) a semicompressible gasket material, (2) compression flanges, and (3) attachments or other devices for applying compressive forces. Gaskets, as well as other static seals, are of two types; face gaskets that are squeezed between two flange faces, and diametrical gaskets that are squeezed between two flange raised face diameters. The basic gasket material may be a resilient material, an elastomer, a plastic coated metal, or a metallic compound or alloy. The gasket may be of the crushable type (with all sealing supplied by the applied compressive forces) or may be of the "self-energizing" type (with some of the sealing force supplied by pressure from the contained fluid). The basic function of the gasket seal is effective when all of these elements are properly combined. The gasket material will plastically flow to fill all of the asperities of the mating surfaces to the extent required to meet the no-leakage requirements of the fluid system.

Basic Gasket Requirements. One of the most elementary design considerations is that the configuration (geometry and dimensional requirements) be suitable to the application. Loss of flatness, nonparallelism, and improper surface finish and/or thickness can result in a nonuniform application of the compressive forces. The resulting distortion, caused by nonuniform stress, can with time result in molecular or viscous leakage. Structural integrity, with respect to both static and dynamic physical properties, is considered to be a prime requirement. Creep and cold flow of elastomeric materials and Teflon can cause lateral expulsion of the gasket material — resulting in loss of the required compressive loading. Contamination can also affect the seal integrity.

Basic Flange Requirements. The primary design requirements for flanges are: (1) choice of proper material, (2) thickness, (3) bolt circle diameter, and (4) the most suitable finish of that area for gasket interface. Configuration consideration should include location and control of dimension of any required grooves for flanges designed for O-ring seals. One of the salient features of many gasket designs is the compressive force applied by these grooves; this is extremely significant with those gaskets that are dependent upon the O-ring or similar construction.

Basic Compression Device Requirements. The most common compression device is a group of bolts. The basic design requirement of any compressive device system that may be used is static, but having dynamic structural integrity. However, the number and arrangement of the bolts or other devices should be of prime concern in order to provide adequate uniform compression, removing any possibility of an inadvertent fracture of the flanges.

Environmental Requirements. The separable items that must be considered as environmental influences include: (1) reactions to the system fluids, (2) temperature (system-induced and from the ambient surroundings), (3) pressures (system and external), and (4) mechanical force loading and vibration. The primary consideration, with respect to the system fluid, is that the materials used must be nonreactive to the system fluids. The other environmental effect that requires amplification is mechanical force loading. This includes such external loads as axial force, tension, bending moments, shearing forces, vibration, and other cyclical force application. Application of these forces can lead to distortion because of cold flow or creep, and fracture or rupture as a direct action or as a result of stress fatigue.

DYNAMIC SEALS

What is a Good Dynamic Seal. The description of a dynamic seal is not as simple and straightforward as that of a gasket. Dynamic seals must accommodate both rotary and linear motion. The sealing mechanism may consist of slingers, controlled flow (labyrinth) joints, sliding contact seals, and linear reciprocating motion bellows. Dynamic seals, like static seals, may be face or diametrical seals. With the exception of the bellows type, dynamic seals are unlike static seals in that they are not normally designed to fill all of the surface asperities. Therefore, they are not normally absolute seals but function as controlled leakage devices.

The two basic considerations in the design of a dynamic seal is the allowable leakage rate and the required operating life of the seal joint. Initial leakage rate decreases when the sealing stress is increased.

To simplify the following discussion of fundamental requirements for dynamic seal components, dynamic seals will be considered to consist of two principal components; (1) sealing mechanisms, and (2) housing/shaft combination. Sealing mechanisms will be treated as a broad term that includes bellows, sealing surfaces of labyrinths, bushings and gaskets, and contacting/containing materials that provide the actual seal.

Sealing Mechanism Requirements. A prime design requirement for dynamic seals is that the configuration (geometry and dimensional requirements) be suitable to the intended application. Improper surface mating can result in distortion, excessive leakage, and/or galling and eventual seizure. Failure to require correct material structural attributes, with respect to both static and dynamic physical properties, can result in creep and cold flow, distortion, stress fatigue, and fracture. Creep, cold flow, and distortion can all result in either galling, binding and seizure, or excessive leakage. Inclusion of contamination and unsuitable chemical combinations can result in surface scoring, corrosion, fluid contamination, and other property degradations.

Basic Housing/Shaft Requirements. Primary design considerations of dynamic seals for housings/shafts, like those of sealing mechanisms, include configuration, material composition and physical integrity, and freedom from contamination. The failure modes resulting from violation of these fundamental concepts are repetitive. In addition, special attention should be given to insuring that the shafts are properly designed, i.e., in accordance with specification MIL-G-5514 (ref 17). Deviation from the basic specification can result in resistance to transverse stress and distortion because of unequal thermal expansion/contraction. Also, as many housings are of cast construction, provision should be made to prohibit the use of housings with any degree of porosity, or voids and inclusions. These anomalies can result in a localized reduction in structural strength which may cause increased leakage at operational pressures.

Environmental Considerations. Design considerations with respect to the environment, are the same for the dynamic seal as for the static seal with one major exception — stresses applied by the various elements of the environment (such as mechanical force, pressure, and temperature) can result in binding, galling and/or seizure prior to the occurrence of excessive leakage, and/or fracture. The most insidious of these stresses is differential pressure because of thermal reactions of materials that have mismatched coefficients of thermal expansion. Thermal equilibrium calculations, made to provide operating limits of fluid/ambient atmosphere temperature combinations, should include a safety margin to accommodate frictional heating of thermally distorted sealing mechanism surfaces.

GASKET/SEAL MATERIALS

General. It is always a good design policy to specify the performance desired. Along with this, it is recommended that the responsible design organization, or even the individual designer, avoid specifying how to compound materials or processes. Permit the seal manufacturer to examine the requirements, considering temperature ranges, pressures, and the medium to be sealed, and arrive at a solution to the given problem. It is more than likely that through his vast knowledge, derived from chemical analysis, tests, and actual applications, that the manufacturer is the best source to provide the required compatible seal.

Qualification. The functional requirements are best known to the design engineer. Upon receiving those seals that were recommended and provided by the seal manufacturer, a test should be instigated to expose the seal or seals to the same conditions that would be encountered in actual service. Periodic checks for seal configuration changes should be made and recorded covering the entire temperature range that the seal would "feel" in actual operation. All test data derived should be carefully recorded so that this data may be used as a ready reference for future applications.

Qualification Results. A review of all test data acquired will be the basis for selection of that seal that would best suit a specific design requirement. This data can be reapplied to other seal requirements.

Seal Configurations and Materials. Numerous gasket/seal manufacturers are producing seals in other than the O-ring configuration. They are also producing seals in varied geometry. Some of these configurations are identified as a "V", "U cup", "W", and lip and flange seals. These seals are made from a wide variety of elastomer/rubber materials and some are manufactured from a variety of 300 series and precipitation hardened stainless steels. The basic applications are for dynamic, static, and port seals.

There is also an area where the prime gasket/seal manufacturers have designed, made, and marketed seals primarily for vacuum systems and components working in vacuum systems.

Seal Selection Responsibility. It becomes the responsibility of the design engineer to design his component, realizing its operational environment, and select those gaskets/seals that are best suited for his design configuration.

Seal Interface Compatibility. The designer should be aware that a unique design of the groove, shaft, or bore might be required in special seal applications.

In keeping with the universal byword on standardization, the primary choice of seals should be those that fit MIL-G-5514 (ref 17) specification requirements. The materials from which these seals are made are to be selected for their chemical compatibility to the medium in which they are installed. As an aid to the designer, the following tables should be referred to. These tables are being periodically extended as new compounds are discovered through extensive chemical research. The gasket/seal manufacturers coordinate their efforts with the rubber/elastomer batch material manufacturers in researching better and new compounds in an effort to meet the constantly changing demands of industry.

COMMONLY USED COMPOUNDS

NITRILE (Buna N). Nitrile seals account for the vast majority of elastomeric sealing materials utilized today. This material is resistant to most petroleum products and is used for all petroleum based hydraulic fluids and nonaromatic fuels and solvents. Effective temperature range is -65 to +250°F.

FLUOROCARBON RUBBER. In applications where the temperature is expected to exceed the 250°F mentioned as the upper limit for nitrile compounds, Viton (fluorocarbon rubber) may be used up to a maximum of 400°F. This material has excellent resistance to most petroleum products, including aromatic fuels and solvents, and the high temperature synthetic lubricants.

ETHYLENE-PROPYLENE. For phosphate-ester service, specifically Skydrol 500 now being used in hydraulic systems of all commercial aircraft, ethylene-propylene is the only material which should be considered. Please note that this material is not resistant to petroleum products and will be severely deteriorated if exposed to petroleum base lubricants or fluids. For assembly and lubrication of ethylene-propylene compounds, phosphate-ester base fluids and silicone lubricants are recommended.

CHLOROPRENE (NEOPRENE) RUBBER. Seals of chloroprene are most often used where their combination of moderate resistance to both air (oxygen) and many petroleum products is required. They are also recommended for sealing many of the Freon refrigerants. Effective temperature range: -65 to +300°F.

SILICONE. Where long term exposure to dry heat is expected, silicone seals are suggested. The three materials mentioned above perform best when bathed in a fluid, however, silicone can provide long service at high temperatures without a protective atmosphere of a fluid system. Silicone also has moderate resistance to most petroleum base products. Due to poor abrasion resistance, silicone compounds should be limited to static sealing applications which require good heat resistant material.

Standard compounds in each of the basic elastomers mentioned above are listed for your convenience on the following page. Most of these materials in standard sizes can be obtained from stock or with a minimum delay in delivery. Please note that for military applications, standard military materials may be specified by the applicable AN or MS number listed in the left hand column of the standard military compound chart. When ordering an industrial compound the size as well as the material must be specified.

STANDARD COMPOUND CHART

STANDARD MILITARY COMPOUNDS					
SERIES	BASE POLYMER	DURO-METER	TEMP GUIDE CONT SERV	MILITARY SPECIFICATION	SERVICE
AN6227B AN6230B	NITRILE (BUNA N)	70 75	-65°F to 225°F	MIL-P-5516 Class B (ref 18)	Air Force and Navy hydraulic fluid. MIL-H-5606 (ref 26)
MS28775	NITRILE (BUNA N)	75	-65°F to 225°F	MIL-P-25732 (ref 19)	
MS29512 MS29513	NITRILE (BUNA N)	70	-65°F to 200°F	MIL-P-5315 (ref 20)	Air Force and Navy Aircraft fuel. J P-4, J P-5
MS29561 NAS617	NITRILE (BUNA N)	70	-65°F to 225°F	MIL-R-7362 Type 1 (ref 21)	Synthetic lubricants. MIL-L-7808 (ref 27)
AN6290 MS28776	NITRILE (BUNA N)	90	-65°F to 225°F	MIL-P-5510 (ref 22)	Hydraulic oil. MIL-H-5606 (ref 26)
NAS1593 NAS1595	Fluoro-(1) Elastomer	75	-20°F to 400°F	MIL-R-25897 CL 1 (ref 23)	High temperature, fluid resistant
NAS1594 NAS1596	Fluoro-(1) Elastomer	90	-20°F to 400°F	MIL-R-25897 CL 2 (ref 23)	High temperature, fluid resistant
M83248/1	Fluoro-(1) Elastomer	75	-20°F to 400°F	MIL-R-83248 CL 1 (ref 24)	High temperature fluid, compression set, resistant
M83248/2	Fluoro-(1) Elastomer	90	-20°F to 400°F	MIL-R-83248 CL 2 (ref 24)	High temperature fluid, compression set, resistant
M25988/1	Fluoro-Silicone	70	-80°F to 350°F	MIL-R-25988 CL 1 gr 70 (ref 25)	Oil and fuel resistant
M25988/2	Fluoro-Silicone	75	-80°F to 350°F	MIL-R-25988 CL 3 (ref 25)	Oil and fuel resistant

BASE POLYMER	DURO-METER	TEMP GUIDE CONT SERV	SERVICE AND SPECIFICATIONS
NEOPRENE	70	-65°F to 300°F	Freon 12, weather and salt water resistant. AMS3209
NEOPRENE	70	-65°F to 300°F	General purpose industrial Neoprene AMS3209
ETHYLENE PROPYLENE	80	-65°F to 300°F	Skydrol (1), Cellulube, and other phosphate esters, steam, water, air dilute acids and alkalis
ETHYLENE PROPYLENE	80	-65°F to 300°F	Phosphate esters, water, air, dilute acids and alkalis
NITRILE (BUNA N)	60	-40°F to 250°F	Mineral oil and hydraulic fluids, water, steam, coolants, pneumatic service
NITRILE (BUNA N)	65	-65°F to 225°F	Petroleum base fuel and low temperature resistant. AMS7271
NITRILE (BUNA N)	70	-65°F to 225°F	Commercial low temperature
NITRILE (BUNA N)	70	-40°F to 250°F	Mineral oils, hydraulic fluids, gasolines, and pneumatics SAE 120R Class 1, U. L. (2)
NITRILE (BUNA N)	70	-40°F to 250°F	Mineral oils and hydraulic fluids, pneumatics. U. L. (2)
NITRILE (BUNA N)	85	-20°F to 225°F	For rotary seals. Do not use with stainless steel
NITRILE (BUNA N)	80	-20°F to 250°F	Mineral oils, hydraulic fluids gasolines and pneumatics
NITRILE (BUNA N)	90	-30°F to 250°F	Mineral oil, hydraulic fluids and pneumatics. High extrusion resistance
SILICONE	60	-80°F to 450°F	Air and gases. Static seal only AMS3303
SILICONE	70	-80°F to 450°F	Air and gases, high temperature resistant. Static seal only
SILICONE	70	-80°F to 450°F	Air and gases. Static seal only AMS3304
Fluoro-(1) Elastomer	75	-20°F to 400°F	High temperature oils, aromatic solvents, chemical service
Fluoro-(1) Elastomer	75	-20°F to 400°F	Ultra low compression set
Fluoro-(1) Elastomer	90	-20°F to 400°F	High temperature oils, aromatic solvents, chemical service. AMS7279
Fluoro-(1) Elastomer	90	-20°F to 400°F	Ultra low compression set

(1) Trademark: Viton-DuPont; Fluorel-Minnesota Mining; Skydrol-Monsanto

(2) Recognized under the Component Program of U. L., Inc.

SYNTHETIC RUBBERS

Comparison of Physical Properties																
	Buna N or Nitrile	Buna S	Butadiene	Butyl	Chloroprene	Chlorosulfonated Polyethylene	Ethylene Propylene	Fluorocarbon	Fluorosilicone	Isoprene	Natural Rubber	Polyacrylic	Polysulfide	Polyurethane	Silicone	Teflon
Ozone resistance	P	P	P	GE	GE	E	E	E	E	P	P	E	E	E	E	E
Weather resistance	F	F	F	GE	E	E	E	E	E	F	F	E	E	E	E	E
Heat resistance	G	FG	F	GE	G	G	E	E	G	F	F	E	P	F	E	E
Chemical resistance	FG	FG	FG	E	FG	E	E	E	FG	FG	FG	P	G	F	GE	E
Oil resistance	E	P	P	P	FG	F	P	E	G	P	P	E	E	G	PG	E
Impermeability	G	F	F	E	G	G	G	G	P	F	F	E	E	F	P	G
Cold resistance	G	G	G	G	FG	FG	GE	FP	GE	G	G	P	G	G	E	E
Tear resistance	FG	FG	GE	G	FG	G	GE	F	P	GE	GE	FG	P	GE	P	E
Abrasion resistance	G	G	E	FG	G	G	GE	G	P	E	E	G	P	E	P	E
Set resistance	GE	G	G	FG	F	F	GE	G	GE	G	G	F	P	F	GE	P
Dynamic properties	GE	G	F	F	F	F	GE	GE	P	F	E	F	F	F	P	P
Acid resistance	F	F	FG	G	FG	G	G	E	FG	FG	FG	P	P	P	FG	E
Tensile strength	GE	GE	E	G	G	F	GE	GE	F	E	E	F	F	E	P	E
Electrical properties	F	G	G	G	F	F	G	F	E	G	G	F	F	F	E	E
Water/steam resistance	FG	FG	FG	G	F	F	E	FG	F	FG	FG	P	F	P	F	E
Flame resistance	P	P	P	P	G	G	P	E	G	P	P	P	P	P	G	G

P – Poor　　G – Good
F – Fair　　E – Excellent

GUIDE TO FAILURE ANALYSIS OF FLUID SEALING DEVICES

General. Failure analysis of disabled or malfunctioning static and dynamic seals cannot be readily performed in the conventional manner. That is, it is seldom feasible to remove the suspect item to a laboratory, functionally test it to verify and identify the failure mechanism and cause, and to verify the analysis by disassembly. The removal of the device normally includes disassembly, either partially or totally, which can relieve the failure-inducing stress and/or create additional damage that can obscure the true cause of failure. For this reason, an alternate analysis procedure is recommended below.

Failure Modes and Causes. The predominant failure modes of seals include leakage (permeation, viscous, and molecular flow), mechanical damage (including rupture), fluid contamination, and (for dynamic seals only) mechanical failure such as galling, binding, and seizure. The most common causes of failure are damage during storage and installation. Misapplication and design/fabrication inadequacies are significant factors that are not to be overlooked with seals employing elastomeric materials.

Recommended Failure Analysis Procedure. As removal and partial disassembly of the suspect seal can obscure the true failure cause, the analysis should be initiated with the defective seal remaining installed in the failed condition. The majority of failures are readily visible, or can be located by local analysis (helium sniffer or spot chemistry). The handling and storage history, and installation procedures that have been used should be thoroughly investigated prior to removal of the device. For additional information that is relevant to the cause of failure, the part should be removed for further analysis only after these actions have been completed with unsuccessful results. Additional analytical procedures (if required) include progressive disassembly, examination for dimensional errors and/or damage, chemical and metallurgical examination of all possible corrosive products, anomalous contaminants, and suspect materials of construction. In the event the malfunction is repetitive, uninstalled parts should be subjected to the same detailed analysis.

The following list of failures and associated causes is provided as a guide to be used in the on-the-spot investigation. The list is not a complete inventory of failure modes and causes, and should be extended by investigating personnel with time and experience. The "Associated Causes" are:

1. Damage During Storage and Installation
2. Misapplication
3. Design Inadequacies
4. Manufacturer Fabrication (including process-out-of-control)

COMMON SEAL FAILURES, MECHANISMS, AND ASSOCIATED CAUSES

Failures	Associated Causes			
	1	2	3	4
Leakage				
Permeation				
Excessive Pressure		X		
Overage Elastomeric Material				
Incompatible Gasket Material			X	
Insufficient Sealing Stress	X		X	
Porous Housing Casting				X
Molecular and Viscous Flow				
Damaged Seal Surface	X			X
Contamination	X			X
Insufficient Sealing Stress	X		X	
Dimensional Errors		X	X	
Thermal Distortion		X	X	
Flange Creep			X	
Gasket (Elastomer) Cold Flow			X	
Design Configuration			X	
Strain Due to Applied Mechanical Forces	X	X		
Excessive Internal Pressure		X		
Deteriorated Gasket (Age or Chemical Attack)		X	X	
Misalignment	X	X	X	
Misapplication		X		

Failures	Associated Causes			
	1	2	3	4
Mechanical Damage				
Environmentally Induced Fracture				
Stress Fatigue		X	X	
Misalignment Strain	X		X	X
Transient Mechanical Force Strain		X		
Thermally Induced Strain		X	X	
Excessively Applied Sealing Force	X		X	
Corrosion		X	X	
Rupture				
Excessive Internal Pressure		X	X	
Excessive Temperature		X	X	
Housing Casting Material Anomalies				X
Shock and Impact	X			X
Installation Damage and Misfit	X			
Fluid Contamination				
Particulate				
Included Contamination	X			X
Installation Damage	X			
Corrosion		X	X	X
Material Surface Decomposition		X	X	
Nonparticulate				
Contamination	X			X
Materials Surface Chemistry		X	X	
Mechanical Failure (Dynamic Seals Only)				
Galling, Binding and/or Seizure				
Material Incompatibilities			X	
Thermal Induced Strain		X	X	
Misalignment	X			X
Transient Mechanical Force Strain	X	X		
Dimensional Errors			X	X
Excessive Seal Stress	X		X	
Contamination	X			X
Corrosion and Wear Products		X	X	

REDUCTION OF FAILURE INCIDENCE IN FLUID SEALING DEVICES

Introduction. Because of the limited amount of ALERT reports on seal failures, the following data are based upon industry-wide experience. The general scheme employed is to provide insight into the elimination of those failure causes previously listed under the heading of "Common Seal Failures, Mechanisms and Associated Causes." The organization follows the "Associated Causes" of that listing.

Damage During Storage and Installation. One of the most common causes of seal failure is premature removal of seal components from their protective enclosures, and inadequate protection of the exposed seal components and assemblies. This procedure frequently leads to inclusion of particulate contamination and scuffing of the seal. Damage is also incurred to precision-machined surfaces of the flanges, ports, and sealing surfaces. Another common shop error is the use of tools and installation aids that have burrs and sharp edges which cause inadvertent damage to these same surfaces, both nonmetallic and metallic. Inadequate shop instructions can cause misalignments and application of undue strains, such as excessive sealing force. Not to be overlooked, is the too common omission of required components or the installation of wrong components during assembly. A review of the shop-caused failures, in conjunction with this information, will reveal that properly prepared shop instructions and adequately trained personnel should definitely reduce the number of seal failures.

Misapplication. It is imperative that the system designer be apprised of the thermal and pressure limits which should not be exceeded without causing irreversible damage to the seal. The materials of composition of the seal should also be analyzed in order that the using designer is informed by application notes of limits on allowable fluids. The proscribed fluids should not be limited to those that corrosively or degeneratively attack materials, but should include those fluids that can act as electrolytes with respect to the materials used in the construction of the seal.

This latter information is required to reduce the incidence of galvanic corrosion. The designer, furthermore, must be provided with adequate information to preclude installation/mounting design that will not subject the seal to misalignment or undue mechanical forces due to any of the known or anticipated environments. The above listed design limits should be enforced by system design reviews and/or proof testing in the presence of a seal specialist (as a participator).

Design Inadequacies. Basic seal design problems can be divided into two major areas: (1) material problems, and (2) configuration. One of the more serious material problems is obtaining system compatibility of each material with respect to its chemical composition, interaction, and thermal expansion/contraction matching. Another basic design problem is retained physical integrity (with respect to dynamic physical properties) such as permeability, creep, and cold flow. The problems associated with design configuration are the normal engineering problems of proper geometry and satisfactory tolerances. The user's assurance of a proper solution of these problems is accomplished only by a thorough design review and a proof testing program. This design review should include consultation with material specialists. The prototype testing program is mandatory in confirming or establishing those operational limits that are required for a specific application.

Fabrication Inadequacies. Manufacturer fabrication errors are too often written off by use of the phrase — "processing out-of-control". Unless the cause and effect of these failures are established through mutual cooperation between user and manufacturer, the underlying cause of the malfunction is seldom eliminated. The primary analysis should be based on a mutually acceptable document such as manufacturers' drawings or a configuration analysis of the subject device (prepared as a part of the initial device design review). The analysis of each significant repetitive failure should be submitted to the manufacturer for his rectification. Another factor in controlling manufacturer errors is the continuing knowledge that an adequate process control program is being employed by the manufacturer. This information is obtained by review of processing and its control (as a part of the original design review) and periodic surveillance to assure that all changes in processing and control thereof are acceptable to the user.

Based upon the above actions and statistical failure history, the user can delineate procedures for the proper inspection of seals and seal components at the time of receipt. It is only with continuing surveillance of seal materials that the user can effect control of failures which in part are caused by manufacturer fabrication errors.

Failure Records. Every known failure of a sealing device should be recorded at a central location. The individual records should include source, complete part identification, and failure mode mechanism and cause. Periodically, histograms should be constructed from this information for each seal type that has had any significant usage. The information derived from a review of these statistical charts can be useful in improving user's shop instructions and installation procedures, rectifying errors in application notes, improve basic seal design, eliminate manufacturer process control oversights, and improve the basic specification for the device.

ALERT SUMMARIES

Summaries of ALERT reports issued against Gaskets and Seals are shown below.

GASKETS

ALERT NO. (GIDEP)	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
D7-69-07	DEFORMED FLANGES Incompatibility of materials	Flanges have a lower bearing strength than the gasket material.	Heat treat (T-6) condition of Conoseal gaskets made of 7075-0 material and Teflon coated, will deform reusable mating flanges which have a lower bearing strength than the gasket material.

SEALS

ALERT NO. (GIDEP)	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
MSFC-71-17	SPRING FAILURE Corrosion	Intermediate seal failed on an engine oxidizer.	Investigation revealed that a inconel garter spring (which holds the carbon seal segments in place) had failed due to corrosion caused by galvanic action between the inconel spring and carbon in the presence of moisture.
MSFC-70-09	FUEL LEAKAGE O-ring deterioration	Fuel leakages were discovered on Saturn manifold assemblies.	Failure analysis attributed leakage to O-ring seal deterioration consisting of an increase in hardness and compressive set. Material analysis of the O-rings revealed that a significant amount of plasticizer had been removed because of the solvency effect of the fuels on the O-ring material.
MSFC-71-10, 10A	OUT OF SPECIFICATION Incompatibility of materials	Engineering review revealed that seals used in Apollo program were similar to other seals which had failed LOX impact test.	Seals under question contain K-6 lead-tin alloy coating as did the other seals which had failed to meet LOX compatibility requirements.

SECTION 8
MATERIALS
(GIDEP CODE 501, 502)

8

CONTENTS

INTRODUCTION

Objective. The objective of this section is to identify the major problems associated with use of basic materials and to provide approaches (developed from experience) for dealing with those problems.

Problem Definitions. The problems are defined first by use of specific examples cited in ALERT reports, and then by using the broader base of information available from other industry and government investigations. This section provides information on cleaning and solvents, metallic materials, conformal coating and potting, and nonmetallic materials. Furthermore, cleaning and solvent problems, and titanium (from the metallic materials subsection), are dealt with in depth.

Problem Prevention. Problem prevention is dealt with by providing relevant information with respect to application techniques, design limits, and test/inspection criteria as applicable.

PROBLEM AREA/CAUSE AND SUGGESTED ACTION

Problem areas and causes associated with Materials are shown below. Suggested actions for minimizing the problems are indicated as applicable. For ease of reference, Materials have been placed into four categories: (1) Cleaning/Solvents, (2) Conformal Coating/Potting, (3) Nonmetallic Materials, and (4) Metallic Materials. The "ALERT ITEM NO." relates each entry to the summaries of ALERT reports which are presented in the last portion of the Materials Section.

CLEANING/SOLVENTS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
SOLVENT ATTACKS CONFORMAL COATING Incompatibility	1	1. Limitations of application should be adequately delineated in well defined cleaning/solvent procedure prior to approval for use. Included in this procedure should be a comprehensive listing of those solvent/material combinations that are acceptable. 2. Solvent/cleaning procedures should be monitored by competent personnel to limit inadvertent misapplication due to misunderstanding or lack of specific knowledge of permissible solvent/material combinations and/or specific approved methods.
ALUMINUM CORRODED BY SOLVENT ATTACK Incompatibility	2	
SOLVENT ATTACKS ELASTOMER Incompatibility	3	
SOLVENT ATTACKS PLASTIC Incompatibility	4	
SOLVENT ATTACKS ALUMINUM Incompatibility	5	
SOLVENT ATTACKS PLASTIC Incompatibility	6	
CONTACT CLEANER ATTACKS DIELECTRIC MATERIALS Incompatibility	7	
SOLVENT ATTACKS SILICONE RESINS Incompatibility	8	
SOLVENT CONTAMINATION Manufacturer process control	9	Adequate inspection/sampling at time of receipt and/or release for use.
SOLVENT TRANSPORTS CONTAMINANTS Inadequate cleaning method	10	Documentation of approved cleaning methods and monitoring thereof.

CONFORMAL COATING/POTTING

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
POTTING SOFTENS WITH AGE Basic composition	11	Use only tested and approved materials
POTTING SOFTENS WITH AGE Basic composition	12	Use only reversion resistant polyether based polyurethanes that meet the hydrolytic stability requirements of MIL-M-24041.

CONFORMAL COATING/POTTING

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
ENCAPSULANT CRACKING Excessive temperature	13	Provide thermal limits in instructions and application notes
ENCAPSULANT CRACKING Inadequate process	14	Cure microballoon filled potting materials at as low a temperature as possible to minimize exotherm and shrinkage. Applying and curing resin in successive layers may be necessary to minimize exotherm and shrinkage problems.
CRACKED CONFORMAL COATING High curing temperatures	15	Cure conformal coating/potting materials at as low a temperature as possible to lessen material shrinkage problems. Polyurethanes are susceptible to moisture absorption and may require degassing after application to minimize reaction with absorbed moisture.
COATING SOLVENT ATTACKS COMPONENTS Incompatibility	16	Include list of noncompatible materials in instructions and application notes.
SOFT POTTING MATERIAL Manufacturer error	17	Adequate inspection at time of receipt
POTTING REVERTS BACK TO UNCURED STATE Basic composition	18	When thick sections or total confinement application of RTV silicone rubbers are required, use only RTV silicone rubbers that meet the revision requirements of MIL-S-23586, Grade B1 or B2.
CRACKS IN SOLDER CONNECTIONS Incompatibility	19	Avoid materials that decompose from normal anticipated environments including high humidity
POTTING COMPOUND CAUSES SHORT Incompatibility	20	

NONMETALLIC MATERIALS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
MATERIAL FLAMMABILITY Incompatibility	21	Determine all application limits before approval for usage
CRACKED RUBBER Ozone attack	22	
SILVER WHISKER CONTAMINATION Sulphur attack	23	Do not use sulphur bearing material in proximity to silver or nickel
RADIATION DAMAGED MATERIALS Excessive radiation	24	Identify and control all nonbenign environments

NONMETALLIC MATERIALS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
TEFLON SHRINKAGE Process variables	25	Adequate inspection at time of receipt
FUNGUS NUTRIENT MATERIALS Inadequate specification limits	26	Verify significant material parameters at time of receipt and approval
DRAWINGS DEPOSIT CARBON Incompatibility	27	Use a different toner
FLUOROLUBE DEGRADATION Chemical attack	28	Forbid use of fluorolube in proximity to aluminum
HONEYCOMB DELAMINATION Voids/environment	29	Perform adequate evaluation tests before approval
TAPE INDUCED STATIC CHARGE Material physical properties	30	
STATIC CHARGE ON ANTISTATIC FILM Incompatibility	31	
STATIC CHARGE ON STYROFOAM Incompatibility	32	
CORROSIVE ACID FORMATION Incompatibility	33	Perform adequate design review before initial approval for usage
ONE COMPONENT RTV SILICONES CAUSE CORROSION Incompatibility of materials	34	Do not use one component RTV silicones that liberate acetic acid during cure; use only the one component silicone sealants that meet the noncorrosion requirements of MIL-A-46146.
PITTING Incompatibility of materials	35	Polyurethane foam material should be inspected periodically for reversion. Inert barrier materials should be placed between polyurethane foam and metallic materials.
SOLVENT CONTAMINATION Incompatibility of materials	36	Use tubing materials that are compatible with solvent being used.
ABS DETERIORATION Unreliable creep data	37	In applications that require a continuous stress state, ABS plastics should be tested in the proposed environment (including air) to determine the age life under the maximum continuous design stress.
POOR ADHESION Improper curing	38	When silicone rubber materials are used as adhesives, the procurement specification should specify testing of the silicone rubber/primer combination.

NONMETALLIC MATERIALS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
PLATING DEFECTS Inadequate process	39	A 50 percent sulphuric acid treatment should be used prior to the electroless copper deposition process when processing flame retardant printed wiring boards.

METALLIC MATERIALS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
TITANIUM EXPLOSION Pyrophoric reaction with LOX and impact	40	Provide designers with listing of application limits for titanium that includes physical and chemical compatibility considerations
TITANIUM CRACKING Notch sensitivity to anhydrous methanol	41	Buffer methanol with controlled amount of water. Refer NASA TDN 3868, "Stress Corrosion and Cracking of Ti-6Al-4V Alloy in Methanol."
TITANIUM FRACTURE Stress corrosion due to contact with N_2O_4	42	Control N"2"O"4" composition. Specify limits on NO content. Refer NASA TM X-59615, "A Case History of Titanium Stress Corrosion in Nitrogen Tetroxide."
MERCURY CONTAMINATION Mercury spillage	43, 44	Limit use of mercury and mercury containing equipment in and around flight hardware. Limits should be based on a safety/hazard analysis of design, fabrication, and usage of hardware.
STEEL EXPANSION JOINT FRACTURE Inadequate design	45	Include metallurgical considerations in design of metallic components that are subjected to nonuniform stress applications

CLEANING/SOLVENTS

General. The following information is primarily concerned with the more commonly used "cold cleaning" techniques in which the cleaning media is used at room temperature. However, this information is applicable for use at elevated temperatures provided that proper precautions are taken with respect to acceleration of attack and other thermally induced side effects, such as breakdown, are taken into account. The well known laboratory rule that the rate of action doubles with each 10°F increase in temperature can be used as a general guide. But the thermal characteristics of each cleaning material should be thoroughly investigated prior to use at any elevated temperature.

Why Use Solvents. A solvent, as the name implies, captures a material by dissolving it and causing it to go into solution with the solvent. Theoretically, a solvent will attack a selected material, such as a contaminating film, and remove all of it without damaging the desirable materials adjacent to the contaminant if the proper kind and amount of solvent is used. Subsequent removal of the solute, i.e., solvent plus entrained contaminant, will result in a "clean" surface. This is a common procedure used in construction prior to painting, application of protective conformal coatings, bonding, and also to provide entry for rework and/or failure analysis of defective components. The success in removal of the desired material without damage to the surrounding area is highly dependent on cleaning methodology described in the following paragraphs.

What is a Good Cleaning Method. A cleaning method is that procedure that prescribes and controls that application of a cleaning media for the removal of nondesirable materials such as contaminants. It follows that a good cleaning method defines the applicable cleaning media including required modifications, thermal limits to be observed, required amounts, usage life, or provisions for maintaining the integrity of the media, application methods and control thereof, and subsequent removal of solute, deposits, and other debris. A better insight into the difference between good and inferior cleaning methods can be gained by a review of some of the undesirable practices and their results.

Sloppy techniques, such as wiping on, can result in damage to adjacent materials and components. Use of excessive temperature can result in decomposition of the cleaning media into highly corrosive monomers and compounds. Furthermore, decomposition products that result from improper usage of cleaning agents can combine with constituents of the environment and/or materials being cleaned and result in undesirable secondary products that can be corrosive, contaminating, or conductive.

Safety/Hazard Considerations. Some of the materials used as cleaning agents are flammable or explosive and many of them are toxic or contact desiccants. Therefore, cleaning procedures should delineate adequate handling precautions with respect to inhalation, ingestion, and/or contact with skin, or mucous membranes to preclude the possibility of injury such as chemical burns.

Other Precautions. As described previously, solvent cleaning will theoretically remove a nondesirable material causing the material to go into solution with the solvent. Subsequent removal of the solute will result in a clean surface. Unfortunately, the solute often acts as a transportation media for the contaminant, and subsequent evaporation of the solvent will deposit the entrained contaminant in another location (often undesirable). An example of this phenomenon is found in the connector section of this handbook. A soldered connector was solvent cleaned to remove flux remaining after the soldering operation. After removal of the solvent, the flux was found redeposited on the contacts of the connector resulting in an open condition upon final installation of the connector.

Another failure-causing phenomenon associated with solvent cleaning is the deposit of latent damage-producing ionic compounds. One example is the cleaning of an open cell elastomer with a chlorinated hydrocarbon. This resulted in the deposit of chlorine ions on and in the surface of the elastomeric material. Subsequent environmental regimes resulted in accumulation of moisture on the surface of the elastomer. This moisture combined with the chlorine ions to form a dilute hydrochloric acid which attacked other adjacent components with disastrous results.

CONFORMAL COATING/POTTING

CONFORMAL COATING

General

Conformal coatings, liquid organic film forming materials, are applied to electronic components and assemblies to provide environmental protection. The liquid coating material is applied in a continuous layer to conform to the shape of the component or assembly. Components mounted on printed wiring boards are the usual form of electronic assemblies that are protected by conformal coatings. In aerospace electronic packaging applications, the conformal coating protects the component or assembly from dust and dirt contamination, moisture and salt air exposure, high altitude flashover, and damage from vibration/shock environments.

Coating Materials

Material Types. Many different liquid organic film forming materials are used as conformal coatings. These coatings vary from simple solutions of organic resins that "set" by evaporation of the solvent carrier, to chemically curing two component materials that must be carefully mixed and cured (polymerized) at room or elevated temperature. Epoxy, polyurethane, and silicone coating materials are predominantly used for conformal coating of aerospace electronic assemblies. The epoxy resin coating materials are only available as two component chemically curing systems. The polyurethane resin coating materials are available as two component chemically curing systems and as one component systems that cure by reacting with either oxygen or moisture in the surrounding air. The silicone rubber coating materials are available as two component chemically curing systems and as one component chemically blocked systems that require exposure to moisture in the air to cure.

All of the epoxy, polyurethane, and silicone coatings are available as 100 percent solids materials (no solvent) and as solvent systems; except for the oxygen and moisture reacting polyurethanes which are available only in solvent systems. The solvent reduced conformal materials produce thin, 0.0005 to 0.003 inch thick, coatings that can be applied by spraying, dipping, or brushing. The 100 percent solids coating materials can be applied in any thickness; normally by brushing and occasionally by dipping. However, special equipment is commercially available for spraying these high viscosity 100 percent solids materials. Most of the conformal coatings will cure in approximately 16 to 24 hours at ambient temperatures, but some of the epoxy and polyurethane coating materials require cures at elevated temperatures as high as 85°C (185°F) for 16 hours. All of the conformal coatings are clear or translucent and component and board markings can be easily read through the applied cured coating.

Environmental Protection

Usage. Conformal coatings are applied to printed wiring boards to protect the copper circuitry on the board's surface from environmental contamination and, in aerospace applications, provide high altitude flashover protection, and anchor small components to the board's surface to prevent component damage during exposure to shock and vibration environments. The surface of the printed wiring board must be cleaned of contaminants such as dust, dirt, finger prints, body oils, and solder flux prior to the application of the conformal coating. Contaminants must be removed so that the conformal coating will adhere to the board's surface and to prevent trapping of contamination underneath the conformal coating. Improperly cleaned boards will present coating problems and have markedly reduced insulating qualities, especially at elevated temperatures or when exposed to humidity. All organic conformal coating materials have reduced insulation resistance properties at elevated temperatures and high humidity levels. A combined elevated temperature and high humidity environment will cause the greatest insulation resistance decrease. Silicone rubber conformal coating materials have the best high temperature insulation resistance properties.

Primers. Primers are generally required to provide adhesion of silicone coatings and are occasionally required for polyurethane coatings. Epoxy coatings do not require primers. A thin, 0.001 to 0.003 inch thick, conformal coating applied to a properly cleaned assembly will provide adequate protection from environmental contamination (dirt, dust, humidity, salt spray, etc.) and will provide flashover protection at high altitudes (low pressures). Heavier coatings may be required to provide mechanical support for components not mounted flush to the board surface. The conformal coating must bridge the gap between the component body and the board surface and attach the component to the board so that relative movement cannot occur between the component and the board. Components not attached to the board surface can experience sufficient movement to cause lead fatigue and component failure during exposure to vibration and shock environments. Conformal coatings should not be depended upon to support the heavier or larger components. Such components, expecially large capacitors which have relatively large bodies and small diameter leads, shoud be filleted or bonded to the board surface for adequate support.

Specifications - Military

MIL-STD-275, "Printed Wiring for Electronic Equipment", specifies that when required conformal coatings shall be per MIL-I-46058, with thickness to be 0.001 to 0.003 inch and assemblies containing components made of brittle materials (glass or ceramic) shall be protected prior to coating with a pliant buffer material such as polyvinylidene fluoride (Kynar), polyethylene terephthalate (Mylar), or silicone rubber. MIL-I-46058, "Insulating Compound, Electrical (For Coating Printed Circuit Assemblies)," covers epoxy, polyurethane, silicone, and polystyrene conformal coating materials to be used in military electronic equipment. Thickness of coating applied to printed circuit assemblies shall be 0.001 to 0.003 inch when measured on unencumbered flat surfaces of the printed wiring board. Fillets between connectors, mounting devices, and components shall be sufficient to provide rigidity and protection for the component and the 0.003 inch maximum does not apply. When applying coatings under MIL-I-46058 to assemblies containing glass diodes, the glass diode shall be fitted with soft vinyl sleevings or such other materials which will not deteriorate any part of the assembly prior to application of the coating. Glass envelope style diodes should have stress relieving bends in their leads so that at least 1/4 inch of lead length lies between the body junction and the point of solder application.

Specifications - NASA

KSC-Spec-Q-0001A, "Coatings Conformal, Protective Environmental, for Printed Circuit Assemblies," covers conformal coatings for use on electrical support equipment. KSC-Spec-E-0001, "Coating, Conformal (Polyurethane), Printed Circuit Assemblies, Procedure For," covers the application of the KSC-Spec-Q-0001 materials to printed circuit assemblies. Conformal coating thickness is specified as 0.001 to 0.003 inch.

MSFC-Proc-257A, "Coating, Conformal, Epoxy, Application Of," specifies the application of a 0.005 to 0.010 inch thick epoxy conformal coating to the back side of printed circuit assemblies and specifically forbids application to the component side. Material specified is MSFC-Spec-222, "Resin Compounds, Electrical and Environmental Insulation, Epoxy;" Type I "Transparent, Unfilled for Coatings, Encapsulation and Impregnation."

MSFC-Proc-293A, "Coating, Conformal (Polyurethane), Printed Circuit Assemblies, Procedure For," specifies the application of a 0.005 to 0.010 inch thick polyurethane conformal coating. Material specified is MSFC-Spec-393B, "Compound, Printed-Circuit Board, Conformal Coating, Elastomeric."

AHB-5355-2, "Conformal Coating and Potting of Electrical and Electronic Assemblies," covers the application of Government or Industry specification conformal coatings (and potting materials) to electrical and electronic assemblies. The thickness specified for conformal coatings is 0.001 to 0.005 inch.

Problem Areas

Problem Areas. Problem areas encountered with conformal coatings can be subdivided into the four following categories:

1. The effects of the coating or coating process on the electrical characteristics of the assembly
2. The effects of the coating or coating process on the components attached to the board
3. Material and process control problems with the conformal coating
4. Material/environment incompatability problems

Degraded Electrical Characteristics. Problems encountered with degraded electrical characteristics (low insulation resistance) are usually due to the entrapment of ionic impurities underneath or in the conformal coating as a result of inadequate cleaning. Occasionally, long term cyclic tests at elevated temperature and humidity levels have caused loss of adhesion between some polyurethane and silicone rubber coatings forming moisture pockets between the board's surface and the conformal coating resulting in lowered insulation resistance. Use of the proper primer will prevent the loss of adhesion between the coating and the board surface, however, primers must be properly cured or separation problems can be encountered between the primer and the conformal coating.

Interaction. Problems encountered with conformal coating/component interactions usually involve either solvent attack on components or mechanical stress on components and solder connections. Since many conformal coatings contain solvents, there are usually problems of solvent attack (see section on cleaning) on components, marking inks, paints, and coatings. The mechanical stress problems are usually associated with the use of thick, hard, conformal coating materials. Extensive glass diode and resistor breakage problems have been encountered on an industry wide basis when thick epoxy and polyurethane (high durometer) coating materials have been thermal cycled.

Solder connection failures have also been encountered during thermal cycling of transistors due to the expansion and contraction of hard conformal coating materials trapped between the board surface and the transistor header.

Coating Thickness. The aforementioned military and NASA specifications have recognized the stress problems associated with thick coatings by limiting conformal coating thickness and requiring the sleeving or "cushion" coating of fragile parts. If heavier coating thicknesses or filleting and bonding are required for component support only the softer, less than 50A durometer, polyurethane and silicone materials should be used.

Improper Material and Process Control. Lack of, or improper, material and process control frequently causes conformal coating problems. The use of overaged material has resulted in conformal coatings that are tacky or do not conform to the required hardness value. This is especially true with polyurethanes which are moisture sensitive and slowly lose their reactivity in partially opened cans. Inaccurate weighing, inadequate mixing, and too low cure temperatures or too short a cure time can also result in tacky noncured coatings. Cure temperatures that are too high can cause excessive shrinkage (causing cracks) and/or loss of curing agent (causing tackiness and incomplete cure).

Incompatibilities. Conformal coating/environmental incompatibilities have caused numerous problems. Heavy, multiple coatings of solvent containing materials have caused incomplete cure due to solvent entrapment and subsequent temperature/vacuum environments have caused the conformal coating to bubble up into a foam. Solvent entrapment can also result in outgassing problems wherein the solvent spews out in vacuum and contaminates adjacent surfaces. Flexibilized epoxy coatings, especially those flexibilized with high percentages of polysulfide or polyamide resins, have lowered insulation resistance and have caused equipment electrical malfunctions when exposed to high temperature and high humidity environments. Polyester based polyurethanes are also sensitive to high temperature and high humidity environments and can revert to a liquid after long exposure to these conditions.

POTTING

General

The term "potting" in its strictest technical sense refers to the embedment of a component or an assembly of components in a permanent container (pot) using a liquid resin that is subsequently cured (polymerized) into a solid. The term "potting" in its broadest usage covers all the processes wherein a component or assembly is impregnated with, encapsulated, or embedded in a liquid resin that is subsequently cured. For the purposes of this discussion, "potting" will be used in its broadest sense. Potting is used primarily to provide electrical insulation and mechanical support to components and assemblies, and to provide a heat conduction path so that the heat generated in a power component can be safely conducted away (especially when the component is operated in a vacuum environment where convection cooling is absent). Potting, in foam materials, is sometimes used to insulate components from an external heat source. The thermal conductivities of the various organic potting materials can be significantly increased by the addition of filler materials.

Materials

Epoxy Resins. Epoxy resins, because of their over-all excellent electrical, mechanical, and physical properties, are the most widely used materials for potting of electronic modules and other assemblies of electronic components. The basic epoxy resin can be almost endlessly modified through the use of selected fillers, flexibilizers, modifiers, copolymers, and curing agents to make literally hundreds of different epoxy formulations. The epoxy formulations can vary from semiflexible compounds with low physical properties to hard rigid materials with exceptionally high strength properties. Almost all of the epoxy potting compounds are two component materials that must be accurately mixed and properly cured. Some of the newer formulations are one component and require high temperature cures.

Polyurethane Resins. Polyurethane resins in the form of lightweight foams and as solid elastomers (rubbers) are used for potting of electronic modules and other assemblies of electronic components. In addition, a major usage for the solid elastomers is in the potting (molding) of cable/connector terminations. Compared to the epoxies, very few polyurethane potting compounds are used. Basically, the most widely used polyurethane foams are in the 2 to 10 pound per cubic foot density range and the solid elastomer materials are almost all unfilled compounds that vary in hardness from 50 to 95A durometer. Almost all of the polyurethane potting compounds (including the foams) are two component materials that must be accurately mixed and properly cured (however, most of the two component polyurethane elastomers can be purchased in frozen, premixed cartridges). One component high temperature curing polyurethanes are now commercially available.

Silicone Rubbers. Silicone rubbers, seldom used for potting of modules and assemblies, are most widely used for potting of connectors, high voltage equipment, and high temperature devices. The silicone rubbers vary in hardness from 25 to

75A durometer and most, but not all, of the potting formulations contain fillers. Almost all of the silicone rubber potting compounds are two component materials that must be accurately mixed and properly cured. One component, high temperature curing silicone rubber potting compounds are now commercially available. One component, chemically blocked materials, that cure at room temperature when exposed to atmospheric moisture are occasionally used as potting compounds with depths restricted to one quarter inch or less.

Problem Areas

Problem Areas. Improper cleaning and inadequate material and process control can result in the same types of problems with potting materials as with conformal coatings. In addition, potting materials have many of their own problems that are characteristic of the particular potting material used.

1. Epoxy Resins. The epoxy curing reaction is exothermic and many problems have been encountered with high exotherms causing both heat damage to components and cracks in the potting material. The faster, so called room temperature curing, epoxy systems are the worse offenders and attention should be paid to the mass of resin, mold material, mold temperature, and resin temperature when these curing agents are used. High exotherms or high curing temperatures cause increased shrinkage of the resin and increased internal stress on components. The use of metal molds, low temperature preheating of mold and resin, and room temperature gelling will decrease exotherms considerably in unfilled resins. After gelling, the resin system should be heat cured to stabilize properties. The use of filled resins and slower curing agents that require a moderate heat cure will lower exotherms, shrinkage, and stress on components.

   Shrinkage of the resin during cure, coupled with the differences in coefficients of expansion between the epoxy and the components, has caused stresses to be set up in the resin that can break components (usually glass encased diodes and resistors) or crack the resin during thermal cycling. Fragile components should be locally coated with a "cushion" of silicone rubber to eliminate cracking when using rigid epoxy potting materials. Metal inserts, brackets, or other hardware with sharp edges can cause cracking of the resin especially if the resin thickness is nonuniform or if the metal part is asymmetrical.

   Entrapped air in the potting material may cause failure to high voltage components by shorting through the lower dielectric strength air. This is a severe problem in high voltage potted units that must operate at high altitudes (reduced pressure). Internal cracks or separations, due to loss of adhesion, (frequently caused by improper cleaning, or the use of incompatible materials) that occur in transformer windings or high voltage coils will eventually cause internal shorts. All high voltage devices should be thoroughly vacuum impregnated and careful attention paid to materials compatibility.

2. Polyurethane Foams and Elastomers. Polyurethane foam materials require that a certain amount of exotherm be developed during their processing so that the foam will have the required low density. Attempts at foaming small parts, or parts containing metal materials that act as heat sinks, often result in foams that have densities of 40 to 60 pounds per cubic foot instead of the intended 2 to 10 pounds per cubic foot. Some foam systems are highly exothermic and can cause component damage even when small volumes (a few cubic inches) are being foamed. Inadequate venting or the use of too much foam can also result in high density foam problems.

   Polyurethane elastomers are nonexothermic and have very low shrinkage. High coefficients of expansion have resulted in solder connection cracking when polyurethane elastomers are used to embed components strung between two printed wiring boards. Their marginal adherence and reactivity toward moisture have generated voids and bubbles that have caused failure in high voltage devices. Some of the lower durometer materials do not offer sufficient support to large components during shock and vibration environments to prevent fatigued component leads. The polyester polyurethanes can revert to liquids under high temperature, high humidity conditions.

3. Silicone Rubbers. Silicone rubber materials are also nonexothermic, have very low shrinkage, high coefficients of expansion, nonadherence to other materials, and insufficient stiffness to support large components. Primers have to be used to overcome the nonadherence problem. However, there are specific problems with certain types of silicones that are characteristic of their curing mechanisms. One type of one component silicone material reacts with moisture in the air and liberates acetic acid which has caused numerous corrosion problems in various electronic equipments. Most of the two component condensation cure silicone (and the new one component nonacetic acid sealants) emit an alcohol by-product during cure that must be allowed to escape. Curing of this type of silicone in thick sections or totally confined can trap the curing by-product and reversion can occur if this material is subjected to prolonged heating. The reversion resistant addition-cure silicone two component materials are inhibited and do not cure at the interface when in contact with a large number of other rubber and plastic materials. Barrier coatings can be used to prevent inhibition problems from occurring when this type of silicone is used.

SAFETY HAZARD CONSIDERATIONS

Most of the solvents used in the solvent reduced conformal coating materials are flammable and slightly toxic. Adequate ventilation is required for personnel safety, and solvents must be allowed to evaporate at room temperature before the coatings are placed in ovens for curing. All of the base resins, catalysts, curing agents, and hardener portion of all the different conformal coating/potting materials are somewhat toxic and adequate precautions should be taken to prevent inhalation, ingestion, and contact with mucous membranes (and the skin in some cases). The polyurethane foams, conformal coatings, and potting materials contain some free isocyanate and are severe lachrymatorsThese materials and the amine curing agents used with many epoxy materials should be handled only in a chemical hood or other locally exhausted area where the fumes are drawn away from the operator.

Skin contact with the uncured materials (especially epoxy resin materials) should be avoided. Prolonged skin contact and the use of solvents to remove uncured resins from the skin (soap and water or skin creams should be used) can lead to dermatitis problems. When an operator becomes "sensitized" to the epoxy resins (through careless handling) severe dermititis, itching, and swelling can occur to such an extent that this person can no longer work with or around epoxy resin materials.

TITANIUM

Why Titanium. The primary reason for the extensive use of titanium in aerospace applications is that titanium alloys are superior to the most common engineering metals and alloys in strength-to-weight ratios at temperatures ranging from -425° to 1000°F. As an example, titanium alloys may be selected that exhibit twice the strength of aluminum alloys at room temperature. This same alloy exhibits one-half of its tensile strength at 1000°F, while the strength of the aluminum has become neglible at approximately 425°F. When compared to 302 stainless steel, selected titanium alloys have ten times the tensile strength at room temperature and approximately three times at 1000°F. In addition, titanium exhibits much lower coefficient of expansion and thermal conductivity than the more commonly used aluminum and steel alloys. Not to be overlooked is the resistance of titanium to corrosion by most media, including nitric acid, most inorganic salts (such as sea water), and most alkalis. The physical properties of the finished titanium component can be readily tailored by creation of the various alloys (as described in the following paragraphs) plus incorporation of an appropriate heat-treating regime.

Basic Titanium Alloys and Their Properties. The common description for the available titanium alloys is based on the metallurgical phase that is predominant at room temperature. The fundamental metallurgical phase is the hexagonal alpha phase which transforms into body centered beta phase at 1625°F. By inclusion of alloying elements, these two phases are combined to form an intermediate phase, combined alpha-beta. The principal differences between these three basic alloys are defined in the following paragraphs.

Alpha Alloys. These include "commercially pure titanium" which is an alloy of pure titanium with a limited amount of impurities, chiefly oxygen, carbon, and nitrogen. The alpha alloys have highest strength and best oxidation resistance at elevated temperatures in the range of 600° to 1100°F. They display excellent weldability but are difficult to forge because of their low ductility, and do not respond to heat treatment. The alpha form can be promoted and stabilized over a wider range of temperature by addition of oxygen, carbon, nitrogen, and aluminum.

Beta Alloys. These are normally limited to applications that will not be subjected to temperatures in excess of 700°F because their properties become unstable above this temperature. On the other hand, the formability of the beta alloys at elevated temperatures is excellent and they can be readily heat-treated. Alloying elements used to promote beta characteristics include hydrogen, manganese, chromium, iron, molybdenum, vanadium, and columbium.

Combined Alpha-Beta Alloys. These consist of a combination of alpha and beta phases in an allotropic structured matrix which is formed by selective addition of the alloying elements listed in the foregoing paragraphs. The results of these additions is the enhancement of one or more properties associated with the phase that is is normally promoted by the addition. As an example, addition of the proper amount of elemental vanadium promotes generation of the beta associated characteristics of formability at elevated temperatures and heat-treatability. Subsequent addition of aluminum will promote the alpha characteristic of improved hot strength. This sequence of events is used with proper controls to produce the well known titanium alloy Ti-6Al-4V. By judicious selection of alloying additives and techniques, the metallurgist can tailor a titanium alloy with virtually any combination of characteristics associated with alpha and beta phases, such as toughness, high physical strength at either hot or cold temperature, heat-treatability, etc.

Titanium Limitations. Factors that should not be overlooked when specifying titanium is the material's proneness to hydrogen embrittlement, stress corrosion, corrosive attack by stronger acids (such as hydrofluoric), and pyrophoric reaction when contacted by certain materials.

The primary defense of titanium against virtually all of the attaching mechanisms is a tough oxide film that readily forms on titanium surfaces with exposure to air at room temperature. Unfortunately this oxide film can be destroyed by elevated temperature, abrasion, and/or rupturing impact.

The most potentially dangerous of the listed attacking mechanisms is pyrophoric reaction which includes spontaneous explosive conflagration. This reaction can be initiated by contact with fuming nitric acid containing less than two percent water or more than six percent nitrogen dioxide, liquid oxygen on impact, anhydrous liquid or gaseous chlorine, liquid bromine, hot gaseous fluorine, and oxygen enriched atmospheres. Stress corrosion may occur in some alloys if chloride salts are present on stressed parts subsequently subjected to high temperatures.

Fabrication Limitations. In addition to the limitations attributable to the built-in material characteristics and/or caused by the environments that the finished component will be subjected to, the designer should be aware of the following limitations that should be applied to fabrication processes.

Welding. Welding should only be accomplished when using inert gas shielding procedures. This should be done to prevent interstitial absorption of gases, such as hydrogen, and inclusion of other contaminants. It is virtually impossible to nondestructively detect these anomalous inclusions that can result in subsequent failures caused by hydrogen embrittlement and other fracture mechanisms.

Heat-Treating. This operation should not be done using carbonaceous or hydrogenous (cracked ammonia) protective atmospheres. The elevated temperatures will accelerate the uptake of carbon and/or hydrogen which can result in metallurgical phase change or hydrogen embrittlement. Heat-treating combined alpha-beta alloy in a carbon rich atmosphere will result in creation of an outer surface case of alpha alloy.

MEAN COEFFICIENT OF LINEAR THERMAL EXPANSION OF MATERIALS
(10^{-6} in/in/°C)
NONMETALS

THERMOSETS (-30 to +30°C)

Phenolic:	
Unfilled	20-40
Wood-flour filled	37
Asbestos filled	9-40
Flock filled	55
Glass filled	11
Diallyl Phthalate:	
Acrylic-fiber filled	55
Asbestos filled	40
Glass filled	32
Alkyd and Polyester:	
Asbestos filled	36
Glass filled	30
Mineral filled	40
Silicone:	
Unfilled	46
Glass filled	8
MSFC-SPEC-379 type I	250
MSFC-SPEC-379 type II	380
MSFC-SPEC-379 type III	350
Silicone rubber	33
Epoxy:	
Unfilled	45-65
Mineral filled	40
Glass filled	20
Silica filled	25-60
MSFC-SPEC-222 type I	95
MSFC-SPEC-222 type II	125
MSFC-SPEC-222 type III	30
MSFC-SPEC-222 type IV	30
MSFC-SPEC-222 type V	45
Melamine:	
Glass filled	15

CERAMICS (25 to 200°C)

Steatite	7.8
Forsterite	10
Cordierite	2.3
Mullite	5.0
Alumina, 99%	6.7
Photosensitive glass	10

GLASSES (25 to 200°C)

Borosilicate (Pyrex)	5
Fused Quartz	0.6

FLUOROCARBONS

Polytetrafluorethylene (Teflon TFE)	55-60
Tetrafluoroethylene and Hexafluoropropylene (Teflon FEP)	60
Polychlorotrifluoroethylene (Kel-F, Halon, CTFE)	60
Polyvinylidene Fluoride (Kynar)	30
Polytrifluorochloroethylene	70
Chlorinated Polyethers (Penton)	31
Polystyrenes (Bakelite, Catalin, Lustron, Styron)	19-30
Polyethylenes (Bakelite, Tenite, Polyeth, Polythene):	
Low density	80
High density	110-124
0.95 density	150
Polyproplyenes	28-100
Vinyl	30-40
Nylon	18
Polycarbonates (Lexan, Merlon)	46-70
Polymides (Nylon 6/6)	58
Acetals (Delrin, Celcon)	42

ACRYLICS

Acrylate and Methacrylate (Plexiglass)	40-60
Methyl-Methacrylate (Lucite)	40-60
Cellulose Propionate (Forticel)	40-80
Fluorinated Ethylene-Propylene Copolymer	90

POLYURETHANES

Polyurethane Foam (MSFC-SPEC-418)	70

LAMINATES (0 to 60°C)	Lgth	Cross	Thick
XXXP Phenolic Paper	20	30	100
XXXPC Phenolic Paper	20	40	200
FR-3 Epoxy Paper	30	40	100
G-10 Epoxy Glass	11	15	60
MSFC-SPEC-377	15	15	60

Silica, used in amounts up to 70 percent by weight of composite, reduces the thermal coefficient of resin (epoxide, silicone, and phenolic) expansion by a factor of 2.

MEAN COEFFICIENT OF LINEAR THERMAL EXPANSION OF MATERIALS
(10^{-6} in/in/°C)
METALS

Aluminum, pure	Al	24.0	Palladium	Pd	11.9
Antimony	Sb	11.7	Platinum	Pt	7.8
Arsenic	As	3.9	Potassium	K	8.3
Beryllium	Be	12.4	Rhodium		8.0
Bismuth	Bi	13.4	Selenium	Se	3.8
Boron	B	8.3	Silicon	Si	7.4
Brass (67Cu, 33Zn)		19.1	Silicon IC chip		2.6
Brass (80Cu, 20Zn)		18.0	Silver, pure	Ag	18.8
Cadmium, cast	Cd	29.9	Sodium	Na	71.0
Calcium	Ca	25.0	Solder (60Sn, 40Pb)		24.0
Chromium	Cr	8.1	Steel (1010)		15.0
Cobalt	Co	12.0	Steel, soft 1% carbon		11.9
Columbium	Cb	7.2	Tellurium	Te	16.7
Copper	Cu	16.4	Thallium	Tl	11.5
Gallium	Ga	18.0	Tin	Sn	23.4
Germanium	Ge	14.2	Titanium	Ti	7.1
Gold, pure, cast	Au	14.4	Tungsten	W	4.0
Indium	In	32.4	Uranium	U	16.2
Iridium	Ir	6.3	Zinc	Zn	32.4
Iron, pure	Fe	11.9	Zirconium	Zr	10.6
Iron, cast 4% carbon		11.9	Rhodium		8.0
Lead	Pb	28.8	Dumet		7.0
Lithium	Li	55.8	Kovar		5.0
Magnesium	Mg	25.8	Alloy 52		9.5
Manganese	Mn	23.0	Alloy 42		6.6
Molybdenum	Mo	4.9			
Nickel, cast	Ni	13.7			

ALERT SUMMARIES

Summaries of ALERT reports issued against Materials are shown below. They are listed according to Cleaning/Solvents, Conformal Coating/Potting, Nonmetallic Materials, and Metallic Materials. The "ALERT ITEM NO." (first column) refers each ALERT back to the "Problem Area/Cause and Suggested Action" table.

CLEANING/SOLVENTS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
1 R8-68-01	SOLVENT ATTACKS CONFORMAL COATING Incompatibility	During rework, solvent used to remove silicone humidity seal attacked resistor's conformal coating and produced cracks and flakes	Short time immersion of printed wiring boards in hot (100°F) toluene resulted in cracks in silicone based conformal coating. Freon used as a cleaning agent to remove excessive soldering flux, resulted in flaking and cracking of the resistor's conformal coating.
2 MSC-68-03	ALUMINUM CORRODED BY SOLVENT ATTACK Incompatibility	Spacecraft closed-loop fluid system was contaminated and corroded after solvent flushing and cleaning.	Corrosion was caused by a reaction between aluminum and hydrolyzed Freon TF. Accumulation and distribution of the corrosion products resulted in system contamination.
3 MSC 1-23-67	SOLVENT ATTACKS ELASTOMER Incompatibility	Kel-F and other elastomeric materials can degrade with time after cleaning with Cry-oxcide and/or Freons.	Severe swelling and softening of the elastomers has been observed after sterilization cleaning with Cry-oxcide and other halogenated hydrocarbons. This is particularly true when the elastomer is in a location where rapid evaporation cannot occur.
4 KSC-68-03	SOLVENT ATTACKS PLASTIC Incompatibility	Methyl Ethyl Keytone (MEK) cleaning solution used to remove epoxy from plastic panels, disintegrated the plastic material.	Cleaning solution used to remove epoxy ink inadvertently ran down wire-wrap studs and came in contact with the plastic material at the base of the stud. The cleaning material disintegrated the plastic material (polysulfoam).
5 KCS 1-24-67	SOLVENT ATTACKS ALUMINUM Incompatibility	Rubber seal of capacitors mounted on printed wiring board was destroyed after immersion cleaning of assemblies with trichloroethylene.	Internal analysis of the failed capacitors revealed corrosion on the ends of the internal aluminum foils. Chemical analysis established trichloroethylene as a contaminant. Contamination by this solvent caused a chemical reaction with the aluminum which resulted in the destruction of the capacitors.
6 S6-69-01	SOLVENT ATTACKS PLASTIC Incompatibility	Molded cases of resistors disintegrated after immersion in Cobehn without affecting the resistance value	Cobehn is a triply distilled chloroform stabilized with a trace of anhydrous ethyl alcohol and is meant to be used as a fine spray and not for soaking electronic parts in it.

CLEANING/SOLVENTS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
7 KSC-69-03, 03A; KSC-69-09	CONTACT CLEANER ATTACKS DIELECTRIC MATERIALS Incompatibility	Chlorinated hydrocarbon contact cleaner attacks selected dielectric materials and leaves a residual oil film.	Certain chlorinated hydrocarbon based contact cleaners have been found to attack the following list of commonly used dielectric materials: acrylics, ethylene-ethyl acrilate copolymers, polystyrene, polycarbonates, polyvinyl chloride, natural and GRS rubbers, and most of the chlorinated rubbers.
8 J5-69-01	SOLVENT ATTACKS SILICONE RESINS Incompatibility	Silicone resins and/or varnishes used on wirewound resistors are subject to attack by trichloroethane.	Trichloroethane is not compatible with some silicone or modified silicone resins.
9 GSFC-69-03	SOLVENT CONTAMINATION Manufacturer process control	Excessive particulate contamination found in solvent	Trichlorotrifluoroethane Type I for clean room use did not meet particulate matter requirement of MIL-C-81302 (ref 28).
10 KSC-68-05	SOLVENT TRANSPORTS CONTAMINANTS Inadequate cleaning method	Failure of nonhermetically sealed components resulted from solvent transportation of contaminants onto internal contacts.	High failure rate of components due to contact contamination by flux residue reveals that extreme care should be taken when cleaning nonhermetically sealed devices after soldering. Investigation revealed that the contamination of these devices is primarily caused by too much solvent being used when cleaning the connections. After the solvent evaporates, a nonconductive filmy residue of flux remains on the contacts.

CONFORMAL COATING/POTTING

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
11 MAA/AFML-68-01, MSFC-68-27	POTTING SOFTENS WITH AGE Basic composition	Potting flowed and exposed covered connections	Polyurethane potting compound breaks down chemically with time and reverts to liquid state.
12 KSC-71-02	POTTING SOFTENS WITH AGE Basic composition	Potting material on cables reverted to sirupy liquid	Actual revision rate was established as 6 to 8 years depending on location and exposure.
13 MSFC-70-02	ENCAPSULANT CRACKING Excessive temperature	Motor encapsulant (epoxy) cracked during vacuum bake.	Analysis revealed that the epoxy encapsulant would crack and outgas at temperatures above 100°C.

CONFORMAL COATING/POTTING

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
14 MSFC-72-06	ENCAPSULANT CRACKING Inadequate process	A microballoon filled epoxy potting material applied in a thick section around a modular assembly exhibited cracks after thermal cycling.	The microballoon filler material acts as a thermal insulator and increases the exotherm of epoxy resin systems. Thick cross sections or large amounts of these resins have high exotherms, increased shrinkage, high external stresses, and decreased thermal cycling resistance.
15 F3-72-04	CRACKED CONFORMAL COATING High curing temperatures	A polyurethane conformal coating material cracked when processed by the supplier.	The same material processed by the contractor at a lower curing temperature did not crack. Tests showed that 180°F was too high a gel temperature for the material. Vacuum degassing after application may be required to minimize small bubbles which act as stress concentration centers.
16 WS-68-02, 02A	COATING SOLVENT ATTACKS COMPONENTS Incompatibility	Conformal coating attacked dielectric and encapsulant of capacitor	Coating solvent is not compatible with polystyrene
17 KSC 3-22-66	SOFT POTTING MATERIAL Manufacturer error	Type III polyurethane material did not meet Shore hardness requirements	Tests showed a maximum Shore hardness of 73, whereas 83 ±5 was specified.
18 MSFC-72-02	POTTING REVERTS BACK TO UNCURED STATE Basic composition	RTV silicone potting material reverted to a liquid.	Reversion of RTV silicones is caused by entrapment of volatile curing byproducts and subsequent exposure to elevated temperatures.
19 KSC-67-65, 65A, 65B, 65C	CRACKS IN SOLDER CONNECTIONS Incompatibility	Shrinkage of conformal coating results in cracking of solder connections on printed wiring board	The polyether based polyurethane coatings contained an unstable isocyanate component. The isocyanate, when exposed to moisture, breaks down.
20 MSC 7-18-67	POTTING COMPOUND CAUSES SHORT Incompatibility	Potting compound component caused corrosion and shorts by acting as a galvanic couple	Analysis of shorted connectors revealed corrosion associated with galvanic action in areas adjacent to the potting compound which contained acetic acid.

NONMETALLIC MATERIAL

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
21 KSC-67-66A	MATERIAL FLAMMABILITY Incompatibility	NEMA Grade G-10 epoxy-glass board material will burn when ignited by hot wire or flame	Epoxy binder is flammable.
22 CG-70-01	CRACKED RUBBER Ozone attack	Stressed areas of rubber parts cracked after 6-9 months.	It appeared to be ozone cracking of stressed rubber.
23 KSC-69-06	SILVER WHISKER CONTAMINATION Sulphur attack	Silver sulfide whiskers were found on silver-plated connector pins.	Protective cover for connector contained black rubber (neoprene) gasket which was cured with a sulphur compound.
24 KSC-67-64	RADIATION DAMAGED MATERIALS Excessive radiation	During X-ray examination of selected areas of equipment, it was seen that adjacent components (Teflon and transistors) could be damaged.	The excessive radiation was caused by high output of the X-ray tube and the high number of exposures in a concentrated area.
25 MSFC-67-03	TEFLON SHRINKAGE Process variables	Shrinkage of 1/4" to 1-3/4" has been observed in FEP type Teflon insulation of hook-up cabling.	Variation due to differences in processing between various vendors.
26 MSC 3-31-65	FUNGUS NUTRIENT MATERIALS Inadequate specification limits	Tests on materials showed they were not fungus resistant	The tests indicated that the nonnutrient properties generally implied in certain materials are in error.
27 MSFC-68-09	DRAWINGS DEPOSIT CARBON Incompatibility	Drawing prints deposit carbon smears	Reproduction process uses a toner that is carbon based.
28 ARC-68-01	FLUOROLUBE DEGRADATION Chemical attack	A solid residue was observed that was the result of fluorolube degradation	Manufacturer has stated the fluorolube breakdown was possible under certain conditions of time and temperature in the presence of aluminum and moisture.
29 LeRC 1-5-65	HONEYCOMB DELAMINATION Voids/environment	During flight a fiberglas-honeycomb shroud failed to separate from a spacecraft	The available evidence indicates that the most probable cause was extensive separation of the inner fiberglas skin from the honeycomb core in such a manner the skin became entangled with other spacecraft components. The separation was due to explosive expansion of the air entrapped in voids as the vehicle encountered decreasing barometric pressure with ascent.

NONMETALLIC MATERIAL

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
30 D7-69-01, KSC-69-12B	TAPE INDUCED STATIC CHARGE Material physical properties	Tape exhibited sparks or blue corona as it was peeled from the roll	Tests indicate that certain tapes can produce up to 35,000 volts of static charge when peeled from a roll.
31 KSC-70-08	STATIC CHARGE ON ANTISTATIC FILM Incompatibility	Samples of plastic film failed the antistatic test.	Twenty samples of plastic film were removed from roll ends and when measured against the Teflon wheel, accepted charges ranging up to 10,000 volts. Analysis revealed that the polyethylene overwrap negated the antistatic properties of the outer layer of each roll.
32 MSC-70-02	STATIC CHARGE ON STYROFOAM Incompatibility	Styrofoam packing material used to ship ordnance stuck to side of package.	The packing material was found to contain a static charge of 4500 Vdc (neg).
33 JPL 9-29-64	CORROSIVE ACID FORMATION Incompatibility	The resistive element in wire wound resistors failed due to corrosion	PVC label material decomposed in the presence of high temperature (above 200°C) into various organic products, water, and HCL. The corrosive acid (HCL) had penetrated the outer epoxy coating of the resistor and destroyed the resistive element.
34 G7-72-01,01A	ONE COMPONENT RTV SILICONES CAUSE CORROSION Incompatibility of materials	Some one component RTV silicones liberate acetic acid during cure resulting in subsequent corrosion of metallic surfaces.	Corrosion noted on fine copper wires, aluminum connectors, steel containers, and cadmium plated surfaces due to action of acetic acid released from particular RTV silicones during cure, usually because of lack of proper ventilation. This type of material can also cause fracture of stressed high strength steel when applied under atmospheric condition of high humidity.
35 MSFC-A-72-13	PITTING Incompatibility of materials	A stored fuel manifold line made of series 300 corrosion resistant steel was found during inspection for stress corrosion to be severly pitted necessitating scrapping.	Investigation revealed that polyurethane foam used on the supports was in direct contact with the line and had reverted to a powdery and/or gummy substance. Analysis of reverted foam indicated a high chloride content and a pH of 3.0 to 3.5.
36 GSFC-72-02	SOLVENT CONTAMINATION Incompatibility of materials	Solvent (Freon TF) residue contained a high percentage of phthalate esters.	Analysis revealed the phthalate esters had been leached from the polyvinyl chloride tubing used to transfer the solvent.

NONMETALLIC MATERIAL

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
37 MSC-72-04	ABS DETERIORATION Unreliable creep data	Acrylonitrile Butadiene Styrene (ABS) material failed under sustained loads and leaked pottasium hydroxide (KOH).	Tests showed that the published creep data on ABS plastics is not reliable even for normal air exposure. Tests also showed that the yield strength of ABS plastic is reduced to less than 70 percent when exposed for one day to organic acids, alcohols, boric acid, detergents, and solvent fumes.
38 MSC-72-03	POOR ADHESION Improper curing	Silicone rubber adhesive exhibited inadequate adhesion.	Problem occurred during room temperature cure with manufacturer's recommended primers in bonds of less than 0.060 inch thickness. Manufacturer now recommends the use of a different primer when curing at room temperature.
39 K9-A-72-10	PLATING DEFECTS Inadequate process	Voids and defects occurred within the plated-through holes of printed wiring boards.	The printed wiring boards were fabricated from a flame retardant laminate. The voids and defects were attributed to a passive condition of the laminate due to excessive amounts of flame retardant chemicals.

METALLIC MATERIAL

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
40 MSFC-65-02	TITANIUM EXPLOSION Pryophoric reaction with LOX and impact	Titanium alloys are attractive for construction of LOX/LH_2 containers for space vehicle systems because of their high strength-to-weight ratios at cryogenic temperatures.	Titanium is highly sensitive to impact in contact with LOX. The shock stimuli produced by small detonator caps alone were sufficient to initiate explosive reaction of titanium in contact with oxygen. Do not use titanium for this application
41 MSC 7-7-67	TITANIUM CRACKING Notch sensitivity to anhydrous methanol	A titanium fuel tank failed when pressurized with methyl alcohol.	The alloy used (Ti-6Al-4V), under stress, is incompatible with anhydrous methanol and the result is failure because of a stress-corrosion mechanism.
42 MSFC-65-04	TITANIUM FRACTURE Stress corrosion due to contact with N_2O_4	Propellant tanks fabricated from titanium alloy (Ti-6Al-4V) either ruptured or leaked after short term exposure to N_2O_4 at 100°F and stress levels at 90,000 psi.	The probable cause(s) are fabrication processes, stress corrosion, galvanic couple corrosion, or a basic incompatibility of materials. Do not use titanium for this application.

METALLIC MATERIAL

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
43 MSC 2-15-67	MERCURY CONTAMINATION Mercury spillage	Mercury spillage was discovered in and on aerospace hardware. Source of mercury was not determined.	In addition to its toxic hazard, mercury, in either liquid or vapor form, can cause severe corrosion and/or cracking of unprotected nonferrous metals as well as act as an electrical conductor. Restrict usage of mercury and mercury containing equipment in and around flight hardware.
44 MSC-68-04	MERCURY CONTAMINATION Mercury spillage	Mercury was discovered in interior of valves used in an oxygen supply system.	The mercury could have been introduced during original fabrication of the valves or during subsequent disassembly and test. Limit usage of mercury and mercury containing equipment in and around hardware.
45 MSC 6-27-67	STEEL EXPANSION JOINT FRACTURE Inadequate design	Steel expansion joint failed during systems test. A fire which damaged several TV cables and scorched a LOX line was attributed to this failure.	Failure was due to embrittlement of the bellows material (AISI 304) at low temperatures. Increase radius of bends to decrease operational stress or choose different material.

NOTE:
1. Where no ALERT number (GIDEP) exists, the originator and date are shown

SECTION 9
ORDNANCE/PROPULSION
(GIDEP CODES 415, 563, 565)

9

CONTENTS

INTRODUCTION

OBJECTIVE

The objective of this section is to identify the major hazards associated with use of ordnance and propulsion, and to suggest safety and handling procedures (developed from experience) for minimizing those hazards.

SECTION ORGANIZATION

The ordnance/propulsion section is presented with the following organization:

1. Problem Area/Cause and Suggested Action. This tabulation lists the problem area, problem cause, and suggested action for ALERT reports issued against ordnance/propulsion.

2. Ordnance Device Problems/Solutions - Non-ALERT. This listing reflects problems and solutions from sources other than ALERTs.

3. Hazards Associated with Ordnance and Propulsion. This listing reflects experience of hazards, causes, and effects.

4. Safety and Handling Procedures for Ordnance. Specific safety precautions for handling explosives are provided.

5. Sources of Additional Information for Ordnance and Propulsion. A listing of relevant documents (with synopses), associations, and agencies is provided.

6. ALERT Summaries. Individual ALERT reports issued against ordnance/propulsion are summarized.

PROBLEM AREA/CAUSE AND SUGGESTED ACTION

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
INADVERTENT INITIATION Electrostatic discharge	1	Arming and firing circuitry can be designed so that a squib is not armed until just before it is to be fired.
VALVE MECHANISM FAILED TO ACTUATE Malfunction of squib	2	Part application data from the manufacturer can prevent problems of this nature from occurring.
DUDS (NO-FIRES) Poor ignition and propagation characteristics of the primary mix	3	Store devices in a controlled environment and conduct thorough age-testing.
PREMATURE IGNITION Migration of lead azide	4	Explosive bolts should be qualified to different levels of vibration testing since virtually all of them will see some level of this type of environment.
FRACTURED BOLT HEAD High stress and hydrogen embrittlement	5	Basic good design practices for the fabrication of bolts should be followed.
OUT OF SPECIFICATION Short canister life	6	Proper lot acceptance testing will uncover failures of this nature.
DAMAGED MILD DETONATING FUSE Acetic acid reaction	7	Use compatible epoxy compounds.
MATERIAL FAILURE Cracks and deformations	8	Insure mountings are sufficient in flatness and strength to preclude the possibility of fragmentation.
INADEQUATE DOCUMENTATION Propellant blend changes, specification changes, etc; leading to qualification test and lot acceptance test failures		Lot certification identifying device by unique lot number and serial number of acceptable devices. Require active participation of both Quality and Engineering in certification effort. Documentation review prior to each new procurement.
MOISTURE IN HARDWARE Shop air condensation		Require dry N_2 when cleaning and drying parts.
ALCOHOL CONTAMINATION Lack of manufacturing controls		Use of neutron-ray technique. Allow no alcohol or solvents in loading rooms. Require documentation approval prior to manufacturing.
CONDUCTIVE CONTAMINATION IN ELECTRICAL CONNECTOR Conductive gasket in Farady cap shredding		Use dry N_2 to clean part prior to installation.
MANUFACTURING LOSSES Rust and contamination		Use protective bags and desiccant.
MANUFACTURING LOSSES Under/overload of explosive material		Use of X and Neutron-radiographic techniques.

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
INSULATION RESISTANCE Excessive testing at high voltage (500 Vdc)		Require minimal testing to insure proper acceptance/rejection criteria. Test only at lot acceptance and prior to installation (250 Vdc).
SEPARATION SYSTEM FAILURE Free volume excessive in frangible area		Eliminate free volume area with RTV.
ELECTRICAL CONNECTOR INSTALLATION, EXCESSIVE TORQUE REQUIRED Improper identification of rubber O-rings		Require inspection for material composition and hardness.

ORDNANCE DEVICE PROBLEMS/SOLUTIONS - NON-ALERT

SQUIB, PRESSURE

Problem. Prior to vehicle installation of the pressure squib, a resistance check revealed an open circuit. After opening and examining the squib, extensive corrosion and primer flaking were observed. A separation was found between a bridgewire and a connector pin at one weld joint. This pin surface was found to be displaced 0.004 to 0.005 of an inch below the plane which should be formed by the other three pin surfaces.

Solution. As a result of investigation three possible failure modes were revealed:

1. Extensive corrosion
2. Primer flaking
3. Poor welds (revealed by Scanning Electron Microscope).

Corrosion and primer flaking were both found to be due to acid flux contamination. The flux contains chlorides and has a pH value of approximately 1.5. This flux releases HCL when heat is applied during the soldering process. The acid attached the steel pins to the cellulose binder and the cellulose lacquer of the primer.

Eliminating extensive corrosion and primer flaking as possible failure modes would require, at the minimum, changing to resin flux and changing the post material. The undesirable aspects of these changes are that problems may arise from contaminants due to use of resin flux and that the resin flux had a past history of unsuccessful performance in this application. Corrective action should include close surveillance of existing techniques, with special attention paid to improving those techniques wherever possible.

COMMAND DESTRUCT UNIT AND SELF DESTRUCT INITIATOR

Problem. Diodes have been used in the command destruct unit and the self destruct initiator. Existing diodes have been in house storage for several years and can no longer be purchased; nor is there any dimensional/functional substitute presently available for these devices. One diode is used to suppress sparking across the commutator switch for EMI control and another is used to prevent circuit damage from reverse polarity during testing. The latter diode provides single point failue mode which would prevent cycling of safe and arm rotor of each device.

Failure of selected diodes aroused suspicion as to the integrity of the two command destruct units and the five self destruct initiators now in stock. Furthermore, existing parts cannot be reworked because this would destroy soldered connections.

Solution. Special confidence tests are being done on existing diodes to arrive at a reliability figure for the command destruct units and the self destruct initiators currently available. A design change has removed the diode used for reverse polarity protection. Hence, the single diode remaining will not prevent cycling of the rotor if it does fail in use. This is the command destruct unit open circuit failure mode.

CUTTER, 1/16 INCH DIAMETER CABLE

Problem. The shear pin maintaining the piston cutting blade in position prior to actuation of the unit was ejecting from the housing of the cable cutter after the squib was fired. This is undesirable since the small steel pin might jam a mechanism or produce other harmful effects in flight.

Solution. A new configuration has been created to keep the shear pin intact. This configuration specifies that a roll type pin shall be employed in place of the original type pin, and that this roll pin shall be retained in the housing by a 360° controlled peripheral staking of housing material at the shear pin hole.

INITIATOR, ELECTRIC

Problem. During the application of 2×10^5 ergs to determine electrostatic discharge sensitivity, a number of units initiated, although calculations indicated a margin of safety. The initiator utilized a glass-to-metal sealed header assembly pressed into a stainless steel case which contained ignition powder. An external spark gap discharge path was provided. An insulating plastic charge cup was designed to contain the ignition powder, the glass-to-metal seal header was undercut to obtain an interference fit into the charge cup, and the resultant subassembly was inserted into the stainless steel case. Although this increased the effective breakdown path, processing problems such as cracking of the plastic charge cups and smearing of ignition powder along the sides of the header allowed for varying breakdown paths and a very small percentage of failures. Investigation revealed that the powder cavity breakdown path was 2 1/2 times greater than the spark gap breakdown path. This value, however, was still less than the applied voltage.

Solution. A potential solution involves coating the charge cup/header assembly mating surface with an insulating cement which further increased the effective discharge path. This actually increased the voltage breakdown characteristics to values greater than the applied voltage, thereby insuring complete protection.

CAST EXPLOSIVE

Problem. Cast explosive exuded from a device during temperature and humidity cycling tests. It was discovered that an additive (less than 1 percent) was included in an explosive mixture to improve casting and prevent cracking during handling. The additive caused formation of a low melting point eutectic.

Solution. The additive was removed from the mixture.

CARTRIDGE, PRESSURE

Problem. The pressure cartridge was not actuating properly with the application of correct current level. It was determined that the recommended installation torque was being exceeded. The configuration of the cartridge is such that if proper torque is exceeded, the single bridgewire is stretched to the point of fracture in certain instances. In those cases where the bridgewire did not fracture its elongated configuration increased the resistance so that predicted current requirements no longer applied.

Solution. Caution documentation has been put into effect warning that the installation torque is critical and under no circumstances is to exceed 30 in-lb.

EXPLOSIVE SEPARATION SYSTEM

Problem. A payload separation system experienced an incomplete separation during qualification testing in that the outer frangible doubler joining the forward and aft rings did not completely separate upon actuation of the explosive system. This particular qualification unit had been subjected to environmental tests, a separation test, and had been refurbished with new frangible doublers before the second series of environmental and separation tests were performed. An analysis was performed to determine a solution to the problem.

Solution. A series of design changes is currently being put into effect to correct the nonseparation problem. Analysis has indicated that the major problem area is that the pyro tube which houses the dual detonating cord did not fit snugly between the frangible doublers. This tight fit is necessary to insure maximum shock effect during detonation. Tube-doubler clearance should be no more than 0.005 of an inch, and even very slight interference is often desirable. Current design changes will reflect this condition, and qualification testing will be continued.

SEPARATION NUT

Problem. The separation nut base exhibited cracks after functioning of the unit. The separation nut base material was 7075-T6 aluminum.

Solution. Base material was changed to 17-4H stainless steel and no further cracking was observed.

HAZARDS ASSOCIATED WITH ORDNANCE AND PROPULSION

The tabulation shown below will be useful in the preparation of an explosive device hazard analysis. The first column is a listing of Hazards and includes specific characteristics such as acceleration in ft/sec^2, etc. The second column predicts the Source of the hazard. The third and fourth columns list several Causes and Effects of the hazards identified in the first column.

The last three columns have a direct relationship to the Hazard column, however, they may or they may not have a direct relationship among each other.

HAZARD	SOURCE	CAUSE	EFFECTS
DISASSOCIATION, CHEMICAL	Monopropellants, fuels or oxidizers.	Temperature of compound raised to point reaction begins.	Explosion.
			Nonexplosive exothermic reaction.
	Explosives.	Presence of suitable catalyst.	Material degradation.
	Organic materials.	Shock.	Toxic gas production.
	Epoxy compounds.		Corrosion fraction production.
			Swelling of organic materials.
ELECTROMAGNETIC	Radar equipment.	Radar equipment operation.	Initiation of ordnance devices.
	Communication equipment.	Communications equipment operation.	Interference with operation of other electronic equipment.

HAZARD	SOURCE	CAUSE	EFFECTS
EXPLOSION Impact sensitivity, psi; TNT equivalency, lb; temperature, °F	Ordnance or munitions systems. High pressure equipment. Cryogenic liquid system.	Inadvertent activation of: High explosives Propellant explosives or combustible gases in containers or confined spaces. Fine dust and powders. Combustible gases or liquids:. In high concentrations. In presence of strong oxidizers. At high temperatures. Activation of cracked or otherwise defective solid propellant motors. Afterburning of confined combustion products. Delayed combustion in a firing chamber. Cold soaking of solid propellants. Overpressurization of boilers, accumulators or other pressure vessels. Warming closed cryogenic or other system containing highly volatile fluid. Contact between water or moisture with water-sensitive materials such as molten sodium, potassium, or lithium; concentrated acids or alkalis; or similar substances.	Rupture of engines, motors or other pressurized container. Blast: Overpressures (impulse energy). Collapse of nearby containers. Damage to structures and equipment. Propagation of other explosions. Fragmentation: Holing of nearby containers and vehicles. Impact of pieces against personnel, equipment and structures. Dispersion of burning, hot, combustible or corrosive materials. Heat (see heat and high temperature). Dispersion of toxic materials. Injury to personnel.

HAZARD	SOURCE	CAUSE	EFFECTS
HEAT AND TEMPERATURE	Any fuel consuming process.	Fire or explosion.	Ignition of combustibles. Initiation of other reactions.
		Other exothermic reaction.	Melting of metals. Charring of organic materials.
Heat, btu, btu/lb, btu/sq ft, temperature °F, °C.	Other exothermic chemical process.	Heat engine operations.	Increased reactivity. Reduced material strength.
	Electrical equipment.	Electrical energy losses.	Reduced equipment life. Distortion and warping of part.
High Temperature		Aerodynamic or other vehicular friction.	Expansion of solids and liquids.
	Solar energy.	Friction between moving parts or vehicle and surrounding medium.	Increased evaporation rate of liquids.
	Biological or physiological processes.	Gas compression	Expansion may cause binding or loosening of parts.
	Moving equipment or parts.	Inadequate heat dissipation.	Increased gas diffusion. Reduced relative humidity. Increased absolute humidity.
		Cooling system failure.	Breakdown of chemical compounds.
		Welding, soldering, brazing, or metal cutting.	Personnel burns.
		Proximity to operations involving large amounts of heat (radiation, convection, conduction).	Reduced personnel efficiency.
		Immersion in hot fluid.	Heat cramps, strokes, and exhaustion.
		Lack of insulation.	Peeling of finishes, blistering paint.
		Exposure to sun or artificial light.	Evaporation or decreased viscosity of lubricants.
		Hot climates or weather.	Changes in electrical characteristics.
		Human or animal heat output.	Softening of insulation and sealants.
		Organic decay processes.	Opening or closing of electrical contacts due to expansion.

HAZARD	SOURCE	CAUSE	EFFECTS
INADVERTENT ACTUATION		Static electricity discharge	Firing of ordnance devices.
		Lightning strike.	Untimely electrical equipment starts.
		Inadequate electrical insulation.	Endangering of personnel working on circuits or equipment.
		Electrostatic discharge.	
		Faulty connector or connection. Corrosion. Dirt or other contamination. Moisture. Excessive solder. Cut wires.	
		Bent pins. Improper wiring. Improper mating. Worn keyways. Poor alignment devices.	
		Inadequate electrical protection.	
		Overloading electrical equipment.	
		Inadequate heat dissipation.	
		High resistance circuits.	
		Sparking and arcing.	
		Welding or build-up of contacts.	
		Lack of adequate grounding	
		Electrolytic action.	
		Misapplied test equipment power.	
		Photosensitive materials.	
OXIDATION Other than by air	Missile propellants. Welding oxygen. Oxygen for respiratory protective equipment. Laboratory chemicals. Cleaning compounds. Process chemicals.	Chemical combination involving oxidants such as: Oxygen or ozone. Halogens or halogen compounds. Oxidizing acids and their salts. Nitrates, chlorates, perchlorates, hyperchlorates, chromates. Higher valence compounds of mercury, lead, selenium, and thallium.	Increased reactivity of combustibles. Easier ignition. Normally low flammable materials may burn easily. May cause violent or explosive reactions. Partner in hypergolic reactions. Corrosion. Forms explosive gels with some fuels. Deterioration of rubber, plastics, or other organic materials. Almost all volatile strong oxidizing agents except oxygen are toxic.

HAZARD	SOURCE	CAUSE	EFFECTS
REPLACEMENT, CHEMICAL	Fluorine and water. Sodium and water. Nitric acid and water.	Replacement of a chemical radical by a more active one.	Exothermic reactions. Explosions. Violent spraying of corrosive material.
SHOCK Impact energy, lb/sq ft; load, lb, G	Any part or piece of equipment.	Impact. Handling and transportation damage. Blast. Pneudraulic actuated devices. Acceleration. Electroexplosive detonating devices. Water hammer. Vibrations caused by heavy equipment.	Breakage of cable, ropes, chains, pin. Fracture of brittle materials. Detonation of sensitive explosives. Normally closed contacts may open. Normally open controls, valves, contacts may close. Parts may be displaced. Disruption of metering equipment.

SAFETY AND HANDLING GUIDELINES FOR ORDNANCE

The storage, handling, transportation, and use of explosives and ordnance devices is potentially hazardous because of the nature of the materials involved. Explosives can, however, be handled and used safely provided proper precautions and procedures are followed. This section describes procedures for general safety and handling of explosives.

GENERAL

Only duly authorized and qualified personnel shall handle, transport, test, and install explosives and ordnance.

"DANGER EXPLOSIVES, NO SMOKING, EYE PROTECTION REQUIRED" signs shall be posted whenever explosive devices are being unpacked, installed into equipment, or otherwise handled. The sign shall be removed only after the devices have been replaced into approved storage containers, or the installation is complete and devices can be operated without danger to personnel.

No smoking shall be permitted within 50 feet whenever explosive devices are being unpacked, installed into equipment, or otherwise handled.

Matches, lighters, etc. shall not be permitted in areas where explosives are being stored or handled.

Shielding caps shall be provided and shall be placed on electroexplosive devices during shipment, storage, handling, and installation up to the point of electrical connection in the missile.

Only approved electrical devices and mechanical tools will be used (including personally owned items).

Radio, radar, television and other transmissions shall not be permitted near any operation involving electroexplosive devices. The problem of radio frequency excitation of electroexplosive devices involves power density, frequency, tuned circuits, and shielding so that it is difficult to set exact safe distances. However, in the absence of other information, the following tables should serve as a guide.

RADIO TRANSMITTERS

Transmitter Power (watts)	Minimum Distance (feet)
0-25	100
25-50	150
50-100	220
100-250	350
250-500	450
500-1,000	650
1,000-2,500	1,000
2,500-5,000	1,500
5,000-10,000	2,200
10,000-25,000	3,500
25,000-50,000	5,000
50,000-100,000	7,000

FM MOBILE TRANSMITTERS

Transmitter Power (watts)	Minimum Distance (feet)
1-10	5
10-30	10
30-60	15
60-250	30
250-600	45

RADAR TRANSMITTER

Transmitter Power (watts)	Minimum Distance (feet)
5-25	100
25-50	150
50-100	220
100-250	350
250-500	450
500-1,000	650
1,000-2,500	1,000
2,500-5,000	1,500
5,000-10,000	2,200
10,000-25,000	3,500
25,000-50,000	5,000
50,000-100,000	7,000
100,000-250,000	10,000
250,000-500,000	15,000

Note: When the transmission is a pulsed or pulsed continuous wave type and its pulse width is less than ten microseconds, the left-hand column indicates average power. For all other transmissions, including those with pulse widths greater than 10 microseconds, the left-hand column indicates peak power.

PERSONNEL

Only duly authorized and qualified personnel shall install, remove, or handle ordnance items.

"Qualified" in connection with this procedure shall mean personnel trained in the safe methods and procedures of handling, using, and installing explosives.

Ordnance work will not be performed unless a minimum of two authorized and qualified persons are present.

In any location where explosives are stored, used, or installed, personnel shall be restricted to only those necessary to accomplish a specific operation.

Whenever explosive devices are fired in tests, personnel shall be adequately protected from all possible flying particles.

EQUIPMENT (SAFETY)

All persons in the immediate vicinity of explosive devices shall wear safety glasses or other approved eye protection whenever these devices are being unpacked, installed into equipment, or otherwise handled.

Cotton clothing will be worn to minimize static electrical charges.

HANDLING AND TRANSPORTATION

Only duly authorized and qualified personnel shall handle and transport explosives and ordnance.

All electrical bridge circuits shall be received electrically shorted and capped.

Electroexplosive devices are to be picked up one at a time. A check shall be made to see that the shorting plug and cap shielding are in place each time it is handled. The device shall be handled so that the live end does not point towards the handler or other personnel.

Before any electroexplosive device is handled, steps shall be taken to eliminate any difference in potential because of static electricity between the electroexplosive device, the person making the installation, and the item on which the device is to be installed.

Shorting devices and shielding caps shall not be removed during storage except to test continuity, and then only in approved testing areas.

Ordnance items shall not be subjected to heat and, where possible, are to be kept out of the direct rays of the sun.

Except during continuity tests, shorting plugs and shielding caps or other safety devices must be kept in place at all times until the final electrical connection is made. Shorting connections shall short all pins to each other as well as to the body of the device.

Explosives shall be carried only in approved transportation containers which act as RF shields, e.g., metal outer containers. The leads must be shorted and shielding caps in place at all times.

All explosives shall be inspected for damage before their subsequent handling and use. Any damaged items shall be segregated from flight items and cognizant personnel notified immediately.

Ordnance items will not be torqued beyond specifications nor cross-threaded. However, should this occur, the specific individual items will be replaced and properly identified, to preclude their eventual flight use.

STORAGE

Explosives shall be stored either in the original shipping containers or in approved storage containers.

Explosives shall be stored only in assigned magazines or magazettes which can provide the required storage environment, i.e., temperature and humidity.

Magazines shall be locked at all times except when occupied by authorized personnel.

Ordnance devices containing explosives, pyrotechnics, or propellants shall not be left unattended but shall be stored in a proper and safe place when not in actual use.

Careful inventory records should be kept showing the location and ultimate disposition of all ordnance item received.

TESTING

Only duly authorized and qualified personnel shall test explosives and ordnance.

Testing, checkout, or preparation for installation are prohibited in storage magazines.

Disassembly or modification of explosive items shall be performed only on the written request of a qualified ordnance/pyrotechnic engineer.

All testing of explosives, except at installation, shall be performed in approved check-out facilities.

1. All tests shall be accomplished per an approved test procedure.

2. Since many explosive devices are electrically initiated, no electrical potential should be applied to any explosive device where the electrical apparatus is capable of delivering more than 10 milliamps of current. Such testing devices shall be used only if approved by cognizant personnel.

3. All personnel testing explosives shall wear safety glasses.

4. A minimum of two pyrotechnic technicians is required for tests.

5. Indirect methods of test shall be used with shielding adequate to protect all personnel from the effects of premature initiation of any explosive device being tested.

6. Ordnance devices will be installed in approved test fixtures when being tested.

Circuit continuity tests on any electroexplosive device shall be made only with a standard silver chloride cell cap testing device, such as the Alinco Igniter Circuit Tester or the DuPont Blasting Galvanometer. An ordinary voltohm meter must never be used as there is sufficient current output from these meters to actuate most electroexplosive devices.

INSTALLATION

Only duly authorized and qualified personnel shall install explosives and ordnance.

All explosives installations shall be made in accordance with applicable "installation" and/or "test" procedures.

All explosives installations shall be performed under the technical direction of an ordnance/pyrotechnic engineer.

Explosives shall be assembled, tested, and otherwise prepared for installation in approved work areas.

Only personnel necessary for the explosive installation shall be permitted in the vicinity of an explosive installation operation. Any deviation must be necessary, and must have the prior approval of a safety engineer.

Explosives to be installed shall be delivered to the installation site only as required. Any items not installed on the day delivered must be returned to the storage area. Note: Those areas having pad ready explosive magazines (magazettes) may store necessary explosives including spares in these magazettes.

Ensure that all safe/arm devices (e.g., Self Destruct Initiator, Command Destruct Unit, etc.) are in the "safe" condition, with safety pins in place, before installation.

Prior to the handling or installation of explosives, the ordnance/pyrotechnic engineer shall verify that the RF (radio frequency) radiation is either nonexistent or at a "safe" level (as specified for the particular facility involved). Ensure that a "no-switching" period is also in effect.

Whenever explosive devices are being mechanically or electrically installed in a vehicle or test setup, all electrical power to the vehicle or test setup shall be turned off. No electrical switches are to be thrown until the installation is complete. Power shall be kept off and the firing circuit shorted until it is safe to fire.

Immediately before electrical connections are made to any explosive device, the firing circuit to which it is to be connected shall be checked for "NO VOLTAGE" between connector pin sockets and between pin sockets and connector body.

After the installation of explosives, an appropriate warning sign shall be posted to warn personnel of the presence of loaded explosives.

SOURCES OF ADDITIONAL INFORMATION FOR ORDNANCE AND PROPULSION

AIR FORCE DESIGN HANDBOOK

AFSC DH 1-6 (System Safety). Contains safety theories, principles, practices, and experience data applicable to all types of Air Force systems and equipments. It includes safety design data pertinent to aerospace vehicle design, ground equipment design, and facilities design, as well as material on system safety engineering. Design Handbook 1-6 was originally scheduled to appear as AFSCM 80-9, Volume VI.

AFSC DH 2-3 (Propulsion and Power). Contains design data covering aircraft propulsion subsystems and secondary power. It includes criteria on engine selection and installation, and detailed information on turbine and rocket engine design; and on electrical, hydraulic, pneumatic, and mechanical secondary power subsystems. Design Handbook 2-3 supersedes Part D and selected portions of Part C of AFSCM 80-1.

AFSC DH 2-5 (Armament). Contains design data on aircraft weapons, electroexplosive subsystems, and ordnance devices. It includes installation criteria for guns, rockets, missiles, bombs, and fire control systems, and will eventually cover all general design data for aircraft armament systems, including the design aspects of storage, handling, transportation, assembly, and loading of nonnuclear munitions. Design Handbook 2-5 supersedes Chapter E.4 of AFSCM 80-1, Chapter C. 10 of AFSCM 80-6, Part D of AFSCM 80-7, and selected portions of AFSCM 80-8, Volume I.

AIR FORCE MANUALS

AFM 71-4, "Packaging and Handling of Dangerous Materials for Transportation by Military Aircraft."(This is a joint publication and also is listed as TM 38-250, NAVWEPS 15-03-500, DSAM 4145.3, and MCO P4030.19.)It provides instructions for packaging, handling and marketing of explosives, ammunition, flammable liquids, solids and oxidizing materials, corrosive liquids, compressed gases, poisons, and several other articles "not otherwise regulated."It is primarily concerned with transportation by military aircraft.

AFETRM 127-1,"Range Safety Manual." Contains range safety requirements common to all missile launch operations supported by Air Force Eastern Test Range (AFETR). It explains these requirements, their preparation, and to whom they must be submitted. The manual is directive in nature and applies to all range users at or supported by the AFETR, all units using the service of, or providing service to the AFETR, and those national agencies launching vehicles which impact the AFETR.

AFWTRM 127-1, "Range Safety Manual."Contains the requirements covering all aspects of range safety for which the AFWTR is responsible. It explains these requirements, their preparation, to whom they apply; and, where applicable, to whom they must be submitted. This manual is directive in nature and applies to all range users and those agencies performing services for the range.

AFM 127-100, "Explosives Safety Manual." Contains safety criteria for operations involving explosives. Covers general precautions, fire protection, storage, electrical hazards, transportation, site plans, construction (quantity-distance criteria), chemical munitions and manufacturing. This manual supersedes AFM 32-6, 1 November 1961.

AFM 127-201, "Missile and Space Safety Handbook (FOUO)." Explains hazards, operation of missile systems, prevention of mishaps, and preparation of safety survey checklists. Covers human factors, hazards of propellants, characteristics of propellants, cleanliness and decontamination, initiating devices, detection and protective equipment, facilities, and "miscellaneous" hazards (microwave, acoustical, welding, weather, stress concentrations, wind); manual is general and educational. Covers the preparation of safety survey checklists for operational missile and space systems.

AFM 160-39, "The Handling and Storage of Liquid Propellants."This manual is in the Medical Service series and is adapted from a publication of the same title issued by the Director of Defense Research and Engineering in January 1963. It lists twenty-two propellants or groups of propellants, gives their general properties, associated hazards, required safety measures, and transfer, storage, and shipping information.

AIR FORCE REGULATIONS

AFR 66-20, "Designating, Redesignating, and Naming Military Rockets and Guided Missiles."

AFR 127-100, "Responsibilities for the Explosive Accident Prevention Program."

AFR 136-6, "Ammunition and Explosive Materiel Quality Assurance."

AFR 136-8, "Responsibilities for Explosive Ordnance Disposal."

AFR 136-10, "Air Force Explosive Ordnance Disposal Program."

TRADE ASSOCIATIONS

Institute of Makers of Explosives. (420 Lexington Avenue, New York, New York 10017). Their interest is in the safe transportation, handling, and use of explosives.

Association of American Railroads. Under the AAR is a group by the title "Bureau for the Safe Transportation of Explosives and Other Dangerous Articles" located at 2 Pennsylvania Plaza, New York, New York 10001.

US GOVERNMENT AGENCIES

Department of Defense Explosives Safety Board (DDESB). Department of Defense Directive No. 5154.4 of 23 October 1971 established the responsibilities of the DDESB. The board insures the establishment and revision of explosives safety standards, and reviews and evaluates all site plans for construction and modification of explosive sites.

The Air Force Propellant Control Committee. OPR for the committee is the Rocket Propulsion Laboratory (RPL) at Edwards AFB. The committee is established under the provisions of AFR 25-7 by Special Order. The members are from a wide range of activities and include users, quality control, procurement, and control, transportation, safety, contracting, testing, specifications and standards writers, and chemists who are experts in the field of propellants. The committee is a working group set up to discuss and solve problems, disseminate information and is instrumental in the revision of propellant manuals, regulations, and TOs. The SAMSO Staff Safety Office (SE) currently provides a representative to the committee.

MILITARY SPECIFICATIONS, STANDARDS, AND TECHNICAL ORDERS

MIL-STD-172B, "Color Code for Containers of Liquid Propellants."Contains directions for color coding portable containers of liquid propellants. Applies also to exterior containers. Coding is by the use of colored stripes (3 max, 2 min) to indicate:

1. Primary hazard from a safety standpoint.
2. Secondary hazard.
3. If it has monopropellant or pyrophoric properties.

A list of 44 liquid propellants is furnished with their color codes.

MIL-STD-709A, "Ammunition Color Coding."The color coding for service and training ammunition items of issue, including guided missiles, EXCEPT: ammunition of less than 20 MM caliber, blank ammunition, cartridge cases, propelling charges for fixed, semi-fixed, separated and separate loading ammunition, commercial ammunition and explosives, display models, test and experimental ammunitions, devices required to be inconspicuous (booby traps, etc.), atomic weapon materials, fuses, cartridge or propellant actuated devices and components of aircrew escape systems or aircraft external stores ejection systems, and biological warfare ammunition.

MIL-STD-746A, "Radiographic Testing Requirements for Cast Explosives."Covers the requirements for radiographic inspection used in determining the presence of discontinuities in cast explosives.

MIL-STD-841, "Marking of Aircraft and Missile Propulsion System Parts Fabricated from Critical High Temperature Alloys."As the name implies this standard sets the marking requirements for critical high temperature alloys to prevent damage to the parts from standard marking procedures. The alloys requiring special marking are listed.

MIL-STD-1167A, "Ammunition Data Card." Covers general requirements for a data card, tells who is responsible for its preparation, and provides detailed instructions for filling it out. (Examples of completed data cards provided.) Distribution of data cards is also specified.

MIL-STD-1168, "Lot Numbering of Ammunition." Covers the description and use of ammunition lot numbers, propellant lot numbers, and the marking of lot numbers on explosive components, inert components, complete rounds and guided missiles. Guided missile explosive components shall be lot numbered in accordance with MIL-L-9931.

MIL-STD-1314A (Navy), "Safety Precautions for Explosive-Loaded Items."Describes and establishes the fundamental standardized safety precautions necessary for safely loading, assembling, and handling explosive-loaded items.

MIL-STD-1512, "Electroexplosive Subsystems, Electrically Initiated, Design Requirements and Test Methods."This standard establishes the general requirements and test methods for the design and development of electroexplosive subsystems and associated items to preclude hazards from unitentional initiation. These requirements apply to all subsystems utilizing electrically initiated explosives or pyrotechnic components.

MIL-STD-1522 (USAF), "Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems."This standard established the basic system safety criteria for pressurized systems used on Missiles and Space

System - Aerospace Vehicle Equipment (AVE) and its related Aerospace Ground Equipment (AGE). It is applicable to all AVE and AGE which contain pressurized systems, subsystems or components.

MIL-L-9931A, "Lot Numbering, Dating, and Data Cards for Guided Missile Explosive Assemblies, Sub-Assemblies and Parts." The procedures covered by this specification are intended to provide minimum controls for identification of units and groups of units procured by the Air Force. Provides permanent file of data required to maintain administrative and physical control of items entering the Air Force inventory.

AFTO 11A-1-33, "Ground Handling of Aircraft Containing Ammo and Explosive Materials." Provides instructions for ground handling of aircraft containing ammunition and other explosives. Distance requirements are given to show how to minimize damage resulting from accidental discharge. Shows what can be handled in industrial areas.

AFTO 11A-1-47, "Explosive Hazard Classifications Procedures." This TO contains the minimum test criteria for:

1. Bulk explosive compositions and solid propellant compositions.

2. Ammunition and explosives items including fuses, igniters, main explosive charge, gun type propellants, artillery ammunition, pyrotechnics and motors, and rocket ammunition up to 8-inch diameter.

3. Rocket motors or devices containing solid propellants.

OTHER GOVERNMENT CODES, MANUALS, AND REGULATIONS

DOD Manual 4145-26-M, "Contractor's Safety Manual for Ammunition, Explosives, and Related Dangerous Material." This manual covers construction, location, and maintenance of facilities, utilities, and equipment concerned with explosives, ammunition, and liquid propellants. Also covered are quantity-distance siting standards, electrical safety standards, industrial safety standards, intraplant movement, and destruction standards. Although "and Related Dangerous Material" is mentioned in the title, this manual does not give guidance concerning "dangerous materials" and "materials hazardous to health" as defined in paragraphs (A)(ii) and (a)(iii), ASPR 7-104.79.

DOD Manual 4145.27M, "DOD Ammunition and Explosives Safety Standards."Provides uniform safety standards and policies for development, manufacturing, testing, transporting, handling, storing, maintaining, and demilitarization of ammunition and explosives including construction and siting of ammunition and explosives facilities.

DOD Regulations 4500.32-R, "Military Standard Transportation and Movement Procedures." This regulation provides the guidance and general procedures for the movement of explosives and other dangerous articles for the military departments and agencies. It outlines the responsibilities of personnel concerned with the movement and receipt of ammo, explosives, and other dangerous articles. It provides that the shipping activity prepare "Special Handling Data Certification, DD Form 1387-2" for military transport and civilian transport to military installation in addition to DOT labeling.

NASA SP-3071, "ASRDI Oxygen Technology Survey Volume I: Thermophysical Properties."This document is composed of the thermodynamic functions, transport properties, and physical properties of both liquid and gaseous oxygen. The low temperature regime is emphasized. Because the data are detailed beyong that previously available, this handbook should fill an existing need for both the scientific and technical communities.

NASA SP-3072, "ASRDI Oxygen Technology Survey Volume II: Cleaning Requirements, Procedures, and Verification Techniques."This document gives the different levels of hardware cleanliness requirements as functions of the particular oxygen service application, the cleaning methods used to attain the required degree of cleanliness, and the verification techniques presently practiced to establish that the cleanliness level required has been attained. No attempt is made to select recommended cleaning procedures since a basis for such selection is not now available.

Department of Labor Title 29, Chapter XVII "Occupational Safety and Health Administration:, Part 1910, "Occupational and Health Standards", Subpart H, "Hazardous Materials."

Department of Transportation Title 49, Parts 71-79 "Explosives and Other Dangerous Articles," and Part 297,"Transportation of Explosives and Other Dangerous Articles by Motor Vehicles."

R. M. Graziano's Tariff No. 25, "Hazardous Materials Regulation of the Department of Transportation Including Specifications for Shipping Containers." Describes commercial surface transportation regulations for classification, shipping, storage, marking, and labeling.

ALERT SUMMARIES

Summaries of ALERT reports issued against Ordnance/Propulsion are shown below. They are listed according to type of part.

ORDNANCE/PROPULSION

TYPE; ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
SQUIB 1 KSC 5-20-64	INADVERTENT INITIATION Electrostatic discharge	An accident occurred with a Delta solid propellant motor.	Cause of accident was inadvertent initiation caused by a static electricity discharge through the igniter squib from the case to bridgewire lead pin. Tests using a naval propellant plant motor case, with igniter suppressor paddle and live squibs installed, resulted in firing the squibs with an electrostatic charge of 1880 volts applied on the fiber body and aluminum foil of the motor case.
SQUIB 2 K2-70-02, LaRC-70-02	VALVE MECHANISM FAILED TO ACTUATE Malfunction of squib	Valve mechanism failed to actuate although the squibs "fired" (propellant consumed).	Failure analysis revealed this squib type is sensitive to the initial volume into which the squib is fired. When the initial volume is 10 cc, application of 7 volts results in conduction across the leadwires, whereas it takes more than 100 volts when the initial volume is 10 cc. Once conduction across the leadwires begins it causes the potting material to break down, allowing the high pressure gases to escape through the squib preventing valve actuation.
INITIATOR 3 LaRC-70-01	DUDS (NO-FIRES) Poor ignition and propagation characteristics of the primary mix	Time delay initiators exhibited "no-fires" during lab tests	Investigation revealed the no-fires were caused by poor ignition and propagation characteristics of the primary mix (lead-selenium, silicon-silicon-dioxide). This primary mix has good ignition and propagation properties when first produced, but it does not age well.
EXPLOSIVE BOLT 4 LaRC 12-22-66	PREMATURE IGNITION Migration of lead azide	An explosive bolt fired during random vibration test.	X-rays taken after the failure showed that some lead azide had migrated to a position between the metal sleeve which contains the lead azide and the outer metal sleeve of the primer cup assembly. The migrated lead azide initiated the detonation during vibration test.
EXPLOSIVE BOLT 5 JPL-69-01	FRACTURED BOLT HEAD High stress and hydrogen embrittlement	Head of release bolt fractured after 15 hours at 2500 lb tension. The device had a design requirement of indefinitely withstanding sustained tensile loads of up to 4000 lb.	The fracture initiated at the sharp radius between the shank and the end face of the bolt head. Cause of failure is attributed to the high stress concentration of the radius, and to the hydrogen embrittlement of the bolt material.

ORDNANCE/PROPULSION

TYPE; ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
CANISTER 6 KSC 8-23-66	OUT OF SPECIFICATION Short canister life	Rocket propellant canister (used in gas masks) generated excessive heat and burned out in 3 minutes. Specification required the canisters to absorb UDMH for 5 minutes.	Failure analysis revealed traces of potassium in the soda-lime layer of the canisters, and differences in physical make-up between it and other canisters of the same type.
MILD DETONATING FUSE 7 MSC-71-07	DAMAGED MILD DETONATING FUSE Acetic acid reaction	Mild detonating fuse (MDF) was found to be of inferior quality during testing.	Analysis revealed that acetic acid, released during curing of the sealant, reacted with the lead sheath of the MDF to form lead acetate. Further reaction with moisture and CO_2 formed lead carbonate and lead hydroxide causing deep etching, corrosion, and embrittlement of the sheath.
SEPARATION NUT 8 B8-A-72-02	MATERIAL FAILURE Cracks and deformations	Functional separation tests revealed material failures in a separation nut such as cracks and deformations.	Investigation revealed that the aluminum base of the separation nut was incapable of selfcontaining the impacting piston during actuation. Therefore, it became dependent upon the structure to which it was mounted to contain the parts at the pressures generated.

NOTE:

1. Where no ALERT number (GIDEP) exists, the originator and date are shown

SECTION 10
RELAYS
(GIDEP CODE 601)

10

CONTENTS

INTRODUCTION

OBJECTIVE

The objective of this section is to identify the major problems associated with the use of relays and to suggest approaches (developed from experience) to deal with those problems.

SECTION ORGANIZATION

The relay section is presented with the following organization:

General

1. Basic failure problems associated with relays are identified based upon ALERT and industry experience.

2. Where applicable, a screening technique is suggested for detecting finished parts having a potential for failure.

Subtopics - Treatment of Specific Types

1. Relay type background.

2. For those in the process of selecting parts and manufacturers, or attempting to eliminate part problems at the manufacturer levels, a portion is devoted to describing the inner construction of selected types and describing the manufacturing sequence necessary to produce the part. Particular emphasis is given to the design or manufacturing deficiencies associated with the identified failure mechanisms.

3. Basic approaches are provided to assist in developing a competent failure analysis plan where corrective action at the part level is desired. The material is arranged so that one experiencing a specific problem can identify those steps in the failure analysis process likely to reveal that problem.

Relay Types. Relays have been divided into subtopics according to their internal construction. Armature and reed type relays have been discussed in depth. Other subtopics dealing with contactors, time delay, choppers, etc., include only summaries of ALERT reports.

RELAY FUNDAMENTALS

What a Relay Should Do. A relay is basically a remotely controlled, electrically operated switch which contains two or more contacts arranged so as to control external circuits. This broad definition applies to all relays regardless of type and internal construction.

Practical Considerations. Most relay types, with the exception of simple thermal time delay and reed types, are complex electromechanical devices. Experience with these devices has indicated that, because of imperfections in materials and workmanship, a relay cannot be satisfactorily specified by contact rating alone. Physical considerations force us to recognize such compromising characteristics built into a relay as operate and release time, temperature effects on pickup and dropout voltages, dielectric breakdown, contact resistance, and insulation resistance. These characteristics are not simply design controlled, but are directly affected by the materials employed and the care with which the relay is assembled. The factors of design, materials, and workmanship are the ones usually associated with relay failure.

FAILURE MODES

Failure Categories. Part level failure problems associated with relays may be lumped under four basic categories:

1. Failure of contacts to make or break

2. Short

3. Electrical parameter deviation

4. Mechanical anomaly

These categories are used for both latching and nonlatching type relays.

ELIMINATING DEFECTIVES

Problem Solving Approach. The approach taken in this section will be to identify the user-encountered problem areas associated with a particular type of relay, then provide suggestions for eliminating those relays prone to exhibiting these problems at the finished relay level, the design level, and at the manufacturing level.

Finished Relay Level. Recognizing that the typical consumer is faced with using finished devices that are on-hand, information is provided for screening — sorting the bad ones from the good. Suggestions are made for subjecting the relays to environmental stresses (capable of identifying defective units, but well within the safe operating margins for properly made units). This reliability technique has found use not only for sorting, but for providing assurance that the manufacturer has controlled his processes.

Design Level. While screening has proven to be an effective reliability tool, it does not correct the fundamental problems of design compromises and worse yet — design deficiencies. Certain design compromises are inevitable, however, reliable equipment can be built if these compromises are recognized and proper precautions are taken in the equipment design to minimize the effects of these compromises. Design deficiencies must be identified and eliminated at the manufacturer's facility.

Manufacturing Level. The most carefully conceived design can be brought to nought if it is manufactured in an environment lacking necessary controls over critical materials and processes, and allowing substandard workmanship. Again, defectives produced as a result of these conditions can be removed using a screening, but since no screen is 100 percent effective, a more desirable technique for removing these potential reliability degraders is to take action to correct these manufacturing conditions by applying controls and providing inspection points.

FAILURE ANALYSIS

Objective. A primary objective of failure analysis is to identify failure mechanisms at a level such that corrective action is feasible. Knowing nothing more about a relay than that it is shorted does not allow effective corrective action. If we learn that the short is caused by contamination, we now have identified a mechanism suitable for corrective action. The cause of the shorting may be eliminated by process changes, added controls, use of different materials, suitable screens, or combinations of these alternatives.

Failed Part Rarity. A part in a failed condition must be considered by its owner as a jewel, a "once-in-a-million" occurrence, a phenomenon he may never again be privileged to witness. Only if one starts from that position may there exist a reasonable chance of performing a successful failure analysis.

Failure Verification. After recording all identifying external markings, and performing a thorough external and radiographic inspection, the first requirement is to verify the failure. Too often the wrong part is removed from the circuit or an equipment test error, rather than a part failure, results in a good part being delivered for failure analysis.

Analysis Direction. The process of analyzing a failure, performing those steps necessary on a suspect device which will result in the identification of a specific correctable failure mechanism, requires the coordination of a series of specialized skills by one having knowledge of failure mechanisms, device design, and manufacturing techniques; and the experience necessary to organize this combination of skills and knowledge into a practical plan of action.

When to Analyze. Many part failures occur for which no corrective action is planned to be taken. In many cases it is most cost effective to simply scrap the defective part and replace it with one that performs properly. For those cases where it is necessary to have assurance that future failures will not occur, a portion of this section is devoted to describing some of the considerations involved in performing effective failure analysis.

Reliability/Life. It is anticipated that as a result of this series of actions at the part level (screening, analysis of design and manufacturing, and effective failure analysis) that significant improvement in reliability and life will be realized.

PROBLEM/SCREENING SUMMARY

Scope. This summation is an accumulation of knowledge and experience gained in dealing with relay failures and in avoiding those failures. It addresses itself to the causes and effects of failures, and shows the suggested screens that will allow identification of relays having latent or incipient defects.

This summary is aimed toward identifying relay problem areas and failure causes. Having identified problems, and recognizing that the typical user is concerned with eliminating this problem from a group of relays on-hand, suggestions are made for performing screening. These screening suggestions are based primarily upon industry experience. The problem areas have been grouped under the basic categories of failure of contacts to make or break, short, parameter deviation, and mechanical anomaly.

ALERT Item No. Where directly applicable, the "ALERT Item No." of the ALERT report describing a specific cause for a failure is listed against that cause. Thereby, a cross reference is provided between a specific failure cause found in the "ALERT Summaries" and the broader failure experience/avoidance knowledge shown in this presentation.

PROBLEM AREA/CAUSE AND SUGGESTED ACTION

ARMATURE RELAYS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
FAILURE OF CONTACTS TO MAKE Contamination - between contacts or between pole piece and armature Contamination - moisture freezing on contacts Deformed parts Armature binding Fractured actuator arm Improper armature/pole alignment Oversize/undersize parts	1,2,3,4,5,6,7, 8 9 10 11,12	High and Low Temperature, Run-In, Sinusoidal Vibration, Particle Impact Noise Detection (PIND), Contact Resistance, Pickup Voltage, and Dropout Voltage
FAILURE OF CONTACTS TO MAKE Open coil (broken leads) Shorted coil (insulation breakdown)	8,13	High and Low Temperature Run-In
FAILURE OF CONTACTS TO BREAK Contamination - solder flux on contact Armature binding Fractured actuator arm Oversize/undersize parts	14,15 16,17	High and Low Temperature Run-In, Contact Resistance, Pickup Voltage, and Dropout Voltage
FAILURE OF CONTACTS TO BREAK Fused contacts		Contact Resistance, Pickup Voltage, and Dropout Voltage
SHORT Contamination - between contacts	18,19,20	High and Low Temperature Run-In, Sinusoidal Vibration, Particle Impact Noise Detection (PIND), Contact Resistance, Coil Resistance, Pickup Voltage, and Dropout Voltage
SHORT Fused contacts		Contact Resistance, Pickup Voltage, and Dropout Voltage
SHORT Shorted coil (insulation breakdown)		High and Low Temperature Run-In
SHORT Shorted terminal (metal between terminal and case)	21,22	High and Low Temperature Run-In, Sinusoidal Vibration, Particle Impact Noise Detection (PIND), Contact Resistance, Pickup Voltage, and Dropout Voltage
ELECTRICAL PARAMETER DEVIATION - DECREASED INSULATION RESISTANCE Contamination Defective insulation Improper lead positioning Inadequate contact gap	23	High and Low Temperature Run-In, Dielectric Withstanding Voltage, and Insulation Resistance

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
ELECTRICAL PARAMETER DEVIATION - HIGH OPERATING VOLTAGE Friction on armature (stud assembly)		High and Low Temperature Run-In
ELECTRICAL PARAMETER DEVIATION - HIGH CONTACT RESISTANCE Contamination - on contact surface Contact pressure Organic outgassed products Plated contact surface defects	 24	High and Low Tempeature Run-In, and Contact Resistance
MECHANICAL ANOMALY - CONTACT TRANSFER (during vibration or shock) Excessive tolerances Resonant point in enclosure Resonant point in NO, NC, or common contacts		Sinusoidal Vibration
MECHANICAL ANOMALY - CONTACT CHATTER (during vibration or shock) Broken welds (frame core bracket, etc.) Contact overtravel Excessive tolerances Improper mounting Insufficient actuator bead gap Resonant point in enclosure Resonant point in NO, NC, or common contacts Terminal (with attached contact) rotating in glass seal		Sinusoidal Vibration, and Particle Impact Noise Detection (PIND)
MECHANICAL ANOMALY Cracks in terminal leads (hydrogen embrittlement) Cracks in header glass Dents in case Poor terminal plating	 25	Visual Examination

REED RELAYS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
FAILURE OF CONTACTS TO MAKE Thermal stress or contamination (moisture)	 26,27	Vibration, Temperature Cycle and Run-In (monitor contacts), and Seal. Measure following parameters at room ambient and temperature extremes: Contact Resistance, Pickup Voltage (ampere turns), Coil Resistance, Dropout Voltage (ampere turns), Operate Time, and Release Time. Final Visual

REED RELAYS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
ELECTRICAL PARAMETER DEVIATION - HIGH CONTACT RESISTANCE Loss of mercury	28	Precap Visual, Vibration, Temperature Cycle and Run-In (monitor contacts), X-ray, and Seal. Measure following parameters at room ambient and temperature extremes: Contact Resistance, Pickup Voltage (ampere turns), Coil Resistance, Dropout Voltage (ampere turns), Operate Time, and Release Time. Final Visual

MISCELLANEOUS RELAYS

TYPE	PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
CHOPPER	ELECTRICAL PARAMETER DEVIATION - HIGH CONTACT RESISTANCE Unstable epoxy compound	29	High and Low Temperature Run-In, and Contact Resistance
PHASE SEQUENCE	FAILURE OF CONTACTS TO MAKE Actuator arm fell off	30	High and Low Temperature Run-In, Sinusoidal Vibration, Particle Impact Noise Detection (PIND), Contact Resistance, Pickup Voltage, and Dropout Voltage
THERMAL TIME DELAY	ELECTRICAL PARAMETER DEVIATION - EXCESSIVE TIME DELAY Low heater coil resistance	31	High and Low Temperature Run-In
TIME DELAY	ELECTRICAL PARAMETER DEVIATION - INADEQUATE TIME DELAY Contamination - aluminum particles	32	X-ray, and High and Low Temperature Run-In (monitor each timing cycle)
TIME DELAY	OPEN AND SHORTED COILS Contamination - corrosion by bromide	33	High and Low Temperature Run-In

ARMATURE RELAYS

CHARACTERISTICS

Why Armature Relay. The relay style used in high reliability applications (and considered here) is the balanced armature type because of its demonstrated ability to withstand mechanical shock and vibration. In these relays the armature is pivoted at its center of mass so as to place it in equilibrium with the static and dynamic forces which act upon it during operation. The moving contacts are either mounted on the armature or activated directly by movement of the armature.

Temperature Effects. Almost all armature type relays use copper magnet wire in the coil windings. In such copper windings the coil resistance is directly proportional to the temperature of the windings. The ampere-turns required for the coil to actuate the armature is, therefore, proportional to temperature since the coil resistance, R, varies with coil temperature. To maintain the required ampere-turns, the pickup and dropout voltages will vary over the application temperature range.

Contact Considerations. The most crucial and troublesome area in relay reliability is that associated with the contacts. Much of the problem area results from the user's lack of understanding of the parameters which affect contact performance. As a consequence, contacts are operated under a wide spectrum of load conditions and a multiplicity of performance criteria which, when reviewed singularly or in combination, are inconsistent with the design parameters of the contacts.

There is a great fund of information available on contact theory and the various materials used in obtaining specific contact characteristics. The user of relays in high reliability applications should be thoroughly familiar with this information since reliability is frequently achieved through carefully limiting certain service applications.

Specification Parameters. The above discussion has served to define a few of the characteristics associated with armature relays. These, and other limitations, can be described as specification limits for manufacturers and using designers. Deviations from limitations can lead to equipment failure. The next subsection will describe problems and failure mechanisms found in armature relays caused by design deficiency, lack of process control, and inadequate quality control.

ARMATURE RELAYS

SCREENING INSPECTIONS AND TESTS

Basic Screening. The screening inspections and tests suggested for armature relays included in the Problem/Screening Summary are as follows:

1. Vibration, Sinusoidal
2. High and Low Temperature Run-In
3. Particle Impact Noise Detection (PIND)
4. Electrical Measurements
5. Visual Examination

Objective . The purpose of the screening is to allow detection of parts that: (1) have been improperly processed by the manufacturer, (2) contain misaligned, oversize, or undersize parts, (3) have poor solder or weld connections, (4) contain particulate contaminants, (5) have not been properly adjusted, or (6) have any other anomalies that could result in a failure under normal operating conditions.

Additional Screening. In cases where specific characteristics are critical in the function of using equipment, such as pickup or dropout speed over a wide temperature range, such characteristics should be added to the requirements of these screening tests.

Case Removal/Inspection. The basic approach taken here is to subject each of the devices to a test procedure in order to make a one-by-one acceptance determination. The disadvantage of this approach is the underlying assumption that the internal construction materials, processes, etc. from part-to-part are homogeneous so that the devices can be treated as a uniform lot. If the devices are not produced under similar design criteria and manufacturing controls which permit a heterogeneous lot to exist, a single screening procedure may not be the optimum for all units. For this reason, it is frequently desirable to examine the internal design and construction. This is accomplished, first, by a nondestructive radiographic inspection; and second, by performing a destructive envelope removal or dissection on a limited sample of devices. This procedure is more meaningful if a design/construction baseline has been established as a comparison criterion.

1. VIBRATION, SINUSOIDAL — MIL-STD-202, METHOD 204 (ref 2)

   The purpose of this test is to determine if there is any degradation of mechanical integrity of the assembled device which may result from loosening of components, or which may result from relative motion between components which are not to tolerance or which are improperly assembled. Where these conditions exist, vibration can produce degraded operating characteristics, wear, physical distortion, and often fatigue and failure. The following conditions are suggested:

   a. One sweep, traversed in 20 minutes at rated level
   b. Sweep in critical axis
   c. Contact chatter 10 μsec max
   d. No contact transfer
   e. Energize nonlatch relays during first half of test time and de-energize during the remaining half.
   f. Latching relays should be latched in one position for half the test and latched in the opposite position for the other half (coils de-energized).

2. HIGH AND LOW TEMPERATURE RUN-IN

This test is a combination of miss testing and temperature cycling. It is highly effective in elimination of relays having parts which are not properly aligned, are out of adjustment, contain materials whose coefficients of expansion are improperly matched, or which respond adversely to low or high temperatures.

The suggested test during temperature cycling is as follows:

Step	Ambient Temperature	Time (Minutes) 1st Thru 4th Cycle	5th Cycle
1	+125°C	30 Min	60 Min
2	+25°C	10 Max	10 Max
3	-65°C	30 Min	60 Min
4	+25°C	10 Max	Stabilize

During steps 1 and 3 (fifth cycle), relay should be operated 1 to 3 Hz for total of 5000 operations without misses (2500 operations per step), coils energized with nominal voltage. Contacts should be monitored for contact resistance.

At completion of each 2500 operations and at extreme temperatures, the following measurements should be taken:

Pickup and Dropout Voltage per MIL-R-39016 (ref 29)

Insulation Resistance (Step 1 only) per MIL-STD-202, Method 302, Cond A (ref 2)

3. PARTICLE IMPACT NOISE DETECTION (PIND)

The PIND test is a nondestructive test and is used as a means for assuring internal cleanliness control. Construction and operation of the PIND system is not complex. Mechanical stimulus (2 to 5g at 27 Hz is obtained from two small shakers and transmitted to a combination transducer-mounting fixture through a coupling having low transmissibility characteristics in the ultrasonic frequency range. The relay under test is attached to the transducer (barium titanate ceramic) by means of a spring-loaded holding mechanism. The transducer electrical output is band-passed from 36 kHz to 44 kHz, amplified, and translated to the audible spectrum through use of an ultrasonic translator. This audible output is available either through a head set or loudspeaker. To perform the PIND test, the operator attaches the relay under test to the transducer and listens for the presence of contamination, as evidenced by nonperiodic noise bursts. Data analyzed indicate that PIND is approximately 85 percent effective in locating relays containing particles, and 97 percent effective in not rejecting good devices. Particle masses of 10 micrograms have been detected.

PIND system operation consists essentially of three sub-systems:

a. The driving electronics and exciters for providing input to the test relay.

b. The holding fixture/transducer for detecting the ultrasonic energy generated by particle-to-can impact.

c. The translator for translating the detected energy to the audible spectrum for aural or electrical display.

4. SEAL — MIL-STD-202, METHOD 112, CONDITION C, PROCEDURE IIIb OR IV (ref 2)

a. 1×10^{-8} atm cc/sec max

5. ELECTRICAL CHARACTERISTICS

a. Coil Resistance — MIL-STD-202, Method 303 (ref 2)

b. Pickup and Dropout Voltage — MIL-R-39016 (ref 29)

c. Static Contact Resistance — MIL-STD-202, Method 307 (ref 2)

d. Insulation Resistance — MIL-STD-202, Method 302, Condition A

e. Dielectric Withstanding Voltage — MIL-STD-202, Method 301

(1) Atmospheric pressure

(2) 5 to 10 seconds

f. Operate and Release Time — MIL-R-39016 (ref 29)

6. VISUAL EXAMINATION

a. Identification

b. Defects

c. Damage

ARMATURE RELAYS

DESIGN AND PRODUCTION CONSIDERATIONS

Failures Related to Process. A typical armature relay (Figure 10-1) and a typical assembly flow (Figure 10-2) are presented together with the suggested controls required to assure a reliable product. The "Critical Process" is defined for each of the manufacturing steps. Relationship is established between failure causes and the manufacturing process. Having experienced a specific problem, one could identify those manufacturing steps with potential for contributing to the failure.

Assembly Flow. The manufacturing flow of an armature relay is essentially the same for all manufacturers, differing principally in the degree of process controls and number of production tests. The assembly flow as described is typical of what may be expected for relays of the type produced to meet MIL-R-39016 (ref 29) specifications. Significant variables are listed on the typical flow diagram with those operations that are considered critical for the design of a reliable relay. In-process inspection and testing may vary from one manufacturer to another depending on the exact construction of the relay type.

TYPICAL ARMATURE RELAY DESIGN (Figure 10-1)

ITEM	ITEM NAME	ITEM	ITEM NAME
1	Bobbin	12	Insulating Film
2	Magnet Wire	13	Insulating Thread
3	Core	14	Reinforcing Lead
4	Insulating Wrap	15	Back Stop
5	Pole Piece	16	Return Spring
6	Pusher	17	Armature
7	Frame	18	Pivot
8	Movable Contacts	19	Stationary Contacts
9	Insulation Pad	20	Header
10	Plug		
11	Case		

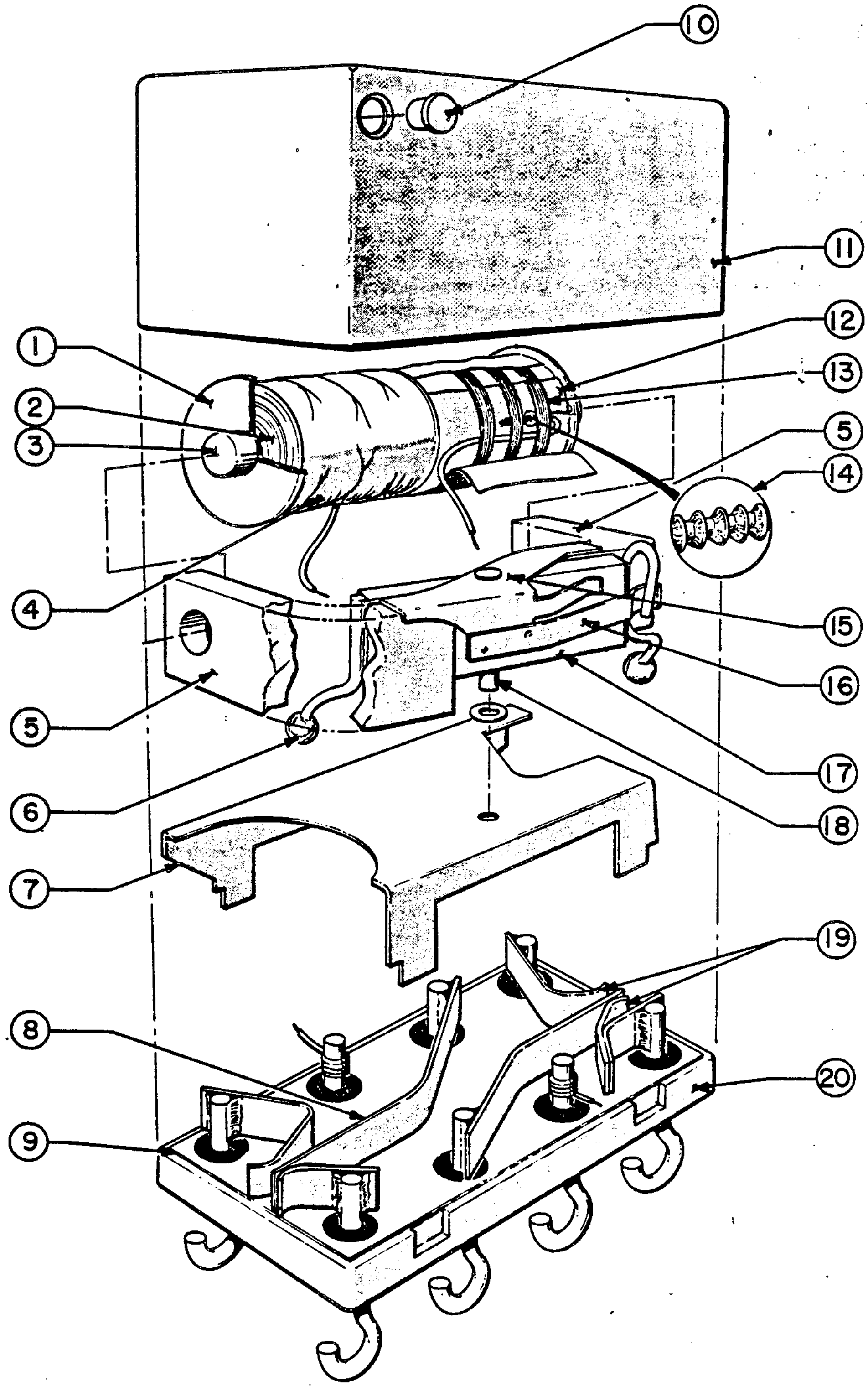

Figure 10-1. Typical Armature Relay (1/2 Crystal Can)

ASSEMBLY FLOW

General. A typical assembly flow (Figure 10-2) is presented together with the suggested controls required to assure a clean, reliable product. It will be noted that the controls predominantly address themselves to the detection of contamination. The assembly operations are performed under semiclean room conditions where such constraints as lint-free garments, filtered air conditioning, prohibition of smoking or eating in assembly areas, and the wearing of special shoe covers are established requirements. Where particular attention must be paid to the control of contamination, laminar flow benches are employed to prevent the introduction of ambient airborne contaminants. The suggested controls have been noted on the assembly flow chart and are considered critical to the fabrication of reliable relays.

Sources of Contamination. Cleanliness is relative and so therefore is contamination. Contamination is a major concern in high reliability relays because it is the prime contributor to relay failures and because it is predominantly introduced during the assembly of the relay. A partial list of contamination sources is provided below:

1. Oxide scale from forging, welding, or heating operations
2. Plastic, glass, ceramic, and elastomer debris from washers, insulation, or spacers
3. Metallic debris generated during machining, grinding, or polishing operations; from interference between moving parts, from improper plating; or soldering or welding operations
4. Fibers from cleaning materials used to wipe surfaces
5. Human hair and dandruff scales
6. Manufacturing and handling dirt
7. Corrosive chemicals from soldering operations
8. Abrasive particles from grinding or polishing operations. Such particles not only constitute harmful contaminants in themselves by causing excessive wear or binding, but produce secondary contamination in the form of metallic particles

Construction Materials. The contamination level in relays is also reduced by the careful selection of materials which are used for the fabrication of the end product. The user should pay particular attention to the materials used for spacers, washers, insulators, and coil insulation as well as plating requirements, before specifying a particular manufacturer's relay for his application. These controls are not indicated on the assembly flow diagram, but are also considered critical to reduction and control of contamination.

FLOW DIAGRAM			RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL	MANUFACTURING OPERATION	CRITICAL PROCESS	FAIL MAKE/ BREAK I	SHORT II	PAR DEV III	MECH ANOM IV
	COIL ASSEMBLY					
Bobbin (1)	Ultrasonic clean	Burred edges and particle contamination	A, C	A	A	
Insulating Film (12)	Insulating film under start lead					
Magnet Wire (2)	Wind coil on bobbin	Damage to wire	C			
Reinforcing Lead (14)	Solder or weld winding to reinforcing lead	Improper solder or weld connection, wire damage, contamination (flux)	A, C	A	A, F	
Insulating Thread (13)	Wind insulating thread					
Insulating Wrap (4)	Wrap insulating film on coil					
	Ultrasonic clean	Particle contamination, residue	A		F	
	Vacuum bake					
	MOTOR ASSEMBLY					
Core (3) Pole Piece (5) Pusher (6) Frame (7) Back Stop (15) Return Spring (16) Armature (17) Pivot (18)	Ultrasonic clean all parts	Burred edges, rough surfaces, plating, particle contamination	A, B	A, B, C	A	
	Spot weld return spring to backstop					
	Spot weld pole piece to frame					
	Spot weld backstop to pole piece	Misalignment, improper weld, weld spatter, particle contamination, plating	A, B, E, G, H	A, B, C	A	E
	Spot weld pushers to armature					
Coil Assembly	Assemble coil to pole piece					
	Ultrasonic clean					

Figure 10-2. Armature Relay - Typical Assembly Flow with Related Problem Codes

FLOW DIAGRAM			RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL	MANUFACTURING OPERATION	CRITICAL PROCESS	FAIL MAKE/ BREAK	SHORT II	PAR DEV III	MECH ANOM IV
	HEADER ASSEMBLY					
Movable Contacts (8) Stationary Contacts (19) Insulation Pad (9) Header (20)	Ultrasonic clean all parts	Burred surfaces, rough surfaces, particle contamination	A	A	A, F, G	B, D
	Install insulation pad					
	Spot weld contacts to header pins	Improper welds, weld spatter, misalignment	A	A	A	B
	Ultrasonic clean	Particle contamination, residue	A	A	A, F	
	Vacuum bake					
	FINAL ASSEMBLY					
	Spot weld motor assembly to header	Improper welds, weld spatter, misalignment, particle contamination, plating	A, E	A	A	
	Demagnetize	(Laminar flow work station)				
	Magnetize for polarized type relay	(Laminar flow work station)				
	Ultrasonic clean	Particle contamination	A	A	A	
	Adjust parameters	(Laminar flow work station)				
	Ultrasonic clean and Cobehn spray	Contamination, corrosion, weld spatter	A	A	A	
	Mechanical and electrical check	Misalignment, binding, hang-up (laminar flow work station)	A, B, G	A	A, C, E G	E, H
Case (ultrasonically cleaned) (11)	Weld header to case	Weld spatter	A, B	A, C	A	
	Repeat mechanical and electrical check					
	Vacuum bake and backfill	Sufficiently dry; inert gas	A	A	A, F, H	
Plug (ultrasonically) cleaned) (10)	Plug and seal					
	Leak test	Hermeticity	A	A	A	
	Paint and identify					
	Screening tests	Mechanical damage				A, B, C
	Package and ship	Mechanical damage				A, B

Figure 10-2. Armature Relay - Typical Assembly Flow with Related Problem Codes

ARMATURE RELAYS

FAILURE ANALYSIS TECHNIQUES

General. Failure analysis is a corrective action-related procedure. Only after knowing why a part failed can action be taken to minimize future failures. Failure analysis findings can show the need for redesign (improvement in materials, processes, and controls) or proper part application.

Predominant Failures. Failures of armature relays most frequently result from problems associated with contamination affecting contact performance or hampering operation of the mechanical moving parts.

CAUTION

EXTREME CARE SHOULD BE EXERCISED TO AVOID INTRODUCING CONTAMINATION INTO THE RELAY.

Opening Techniques. A cut is made around the periphery of the enclosure approximately 3/32 inch above the base of the header. The depth of the cut should not exceed 90 percent of the thickness of the enclosure wall and should be made using a cutting wheel (aluminum-oxide) mounted in table saw fashion.

After completion of the peripheral cut, the entire surface of the relay should be thoroughly vacuum cleaned in a cleanroom environment.

Use a sharp, knife-edged tool to carefully cut through the remainder of enclosure wall.

Failure Analysis Flow. The failure analysis flow (Figure 10-3 which follows) provides for maximum nondestructive evaluation of the failed part prior to the dissecting or depotting operation.

Relationship to Failures. Where it is relevant, each step of the failure analysis procedure (Figure 10-3) is related to one of the four major problem areas and their causes by a coding system which is defined on the foldout in the Appendix. Thus, one experiencing a specific type of failure can identify those steps in the failure analysis most likely to reveal the problem.

TEST/EXAMINATION	PROCEDURE	WHEN FAILURE IS / LOOK FOR: RELATED PROBLEM CODE (see foldout in the Appendix) FAIL MAKE/ BREAK I	SHORT II	PAR DEV III	MECH ANOM IV
NONDESTRUCTIVE MECHANICAL					
External Visual Examination	Note all identifying markings and external damage	A, I, J	A	A, I, J	A, B, C, D
Radiographic Inspection	If fixed focus X-ray used, photograph in three planes mutually perpendicular to vertical axis. (Use for crystal can and larger relays). If Vidicon (imaging) used (1/2 crystal can, TO-5 and other small relays), examine and photograph anomalies as observed.	A, B, I, J	A, B, C	A	
PROBLEM AREA VERIFICATION					
NONDESTRUCTIVE ELECTRICAL					
Functional Testing	All specified electrical parameters. Record data	C, D	B, C, D	B	
Seal Test	Helium mass spectrometer for relays having helium tracer. Those having nitrogen must be tested by Radiflow	A	A	A	
INDUCING FAILURES					
Special Conditioning	Baking, temperature cycling, vibration, and shock as required to confirm problem area				
Radiographic Inspection	Fixed focus or Vidicon as appropriate	A, B, I, J	A, B, C	A	
Functional Testing	All specified parameters. Record data	C, D, I	B, C, D	B	
PROBLEM CAUSE VERIFICATION					
Gas Analysis	Gas chromatograph. Do only if high contact resistance is encountered	A	A	A, H	
Case Removal	See paragraph "Opening Techniques". Inspect for contamination, corrosion, weld spatter, misalignment, binding, broken or fused parts, etc. Use normal and black light.	A, B, E, F, G, H, I, J	A, B	A, B, C, D, E, G, H	B, E, H, I
Function Operation and Testing	Remeasure electrical parameters. Observe contacts and mechanism for signs of binding, sticking, or hang-up while relay is operating	A, B, F, G		A, C, D	E, H
Solvent Rinse, Particle Isolation and Identification	Clean with Freon TF in a chemically clean container. Evaporate and identify particles. (Infrared spectrophotometry, electron beam microprobe, emission spectroscopy, etc.)	A	A	A, F	H
Progressive Disassembly and Inspection	Carefully disassemble mechanism inspecting each portion for wear, corrosion, galling, plating defects, contaminants, etc.	A, E, F, J	A	A, B, C, D, G	B, E, H

Figure 10-3. Armature Relays - Typical Failure Analysis Flow with Related Problem Codes

REED RELAYS

CHARACTERISTICS

Classification. Reed relays are made from one or more reed capsule switches placed inside a common actuating coil. In those cases where the reed capsule switch is used in conjunction with a coil, it is generally classified as a relay; and in those cases where the reed capsule switch is used in conjunction with permanent magnet actuation, it is classified as a magnetic switch.

Operation. A basic magnetic reed switch consists of a pair of low reluctance ferromagnetic, slender flattened reeds, hermetically sealed into a glass tube with a controlled atmosphere, arranged in cantilever fashion so that the ends align and overlap with a small air gap in between. The overlapping ends assure opposite polarity when brought into the influence of a magnetic field. When the magnetic flux density is sufficient, the attraction forces of the opposing magnetic poles overcomes the reed stiffness causing them to flex toward each other and make contact. The restoring force provided by the elasticity of the reeds returns the reeds to their original position when the magnetic field is removed. Reed capsule switches when used within their rated limits generally have contact life ratings in the one to one hundred million cycle range depending on contact voltage and current loads used.

Application Considerations. The reed switch is inherently a low current, low voltage device. Its contact areas are small and contact pressures are low because the reeds become magnetically saturated, therefore, additional contact force cannot be developed by increasing the applied magnetic flux. These factors limit the continuous current rating of the switch. The interrupting rating of the switch is limited by the gap between fully open contacts and by the restoring force provided by the elasticity of the reeds. Low contact pressures and small contact gap between fully open contacts limit the reed capsule switch use in severe vibration and shock environments.

Unpredictable random occurrence of contact sticking inherent in these switches is caused by tiny magnetic wear fragments accumulated at, and sometimes bridging, the contact gap. Arcing caused by dc loads between the contacts causes metal transfer resulting in spike and crater formation which sometimes results in contact sticking due to friction between the spike and coated surfaces. For these reasons application should be limited to those uses where an occasional contact miss is not considered a catastrophic event and those uses where voltage and current loading of the switch contacts minimizes spike and crater formulation. Careful handling of the switch is a mandatory requirement. The switch contact members extend beyond each end of the glass capsule and are used as switch terminals. Bending, cutting, or applying excessive heat to the switch leads during soldering and installation changes the switch operating sensitivity. Operating one reed switch adjacent to another or in a stray magnetic field can also change its sensitivity. Magnetic shielding around reed relays is relatively ineffective in reducing the effects of uniform stray magnetic fields. Reed relays are inherently more sensitive to stray magnetic fields by one or two orders of magnitude than any other type of sealed relay in common use today. The sensitivity is only an order of magnitude greater than earth's magnetic field which results from relative poor magnetic efficiency of a reed relay compared with other types of relays. Stray magnetic fields in the order of 5 to 10 gauss can cause most reed relays to malfunction.

In those special applications where usage of reed switch capsules occur, the above factors should be carefully reviewed and considered with respect to each application prior to usage.

REED RELAYS

SCREENING INSPECTIONS AND TESTS

The following inspections and tests have been found to be effective in detecting and eliminating potential failures. Variation as to levels or durations of tests should be considered to suit those particular applications or performance requirements that apply.

1. VIBRATION, SINUSOIDAL — MIL-STD-202, METHOD 204, TEST CONDITION D (ref 2)

   One sweep 20 minutes; low to high frequency in 10 min, high to low frequency in 10 min

   Sweep to be applied in direction of contact motion

   Contact chatter 10 μsec max

   No contact transfer

   Energize nonlatch relays during 1/2 test time — de-energize during other half

   Latch relays latched in one position for 1/2 test time and latched in other position for the other half (coils de-energized)

2. TEMPERATURE CYCLING AND RUN-IN — MIL-STD-202, METHOD 102, TEST CONDITION C (ref 2)

   While at the high temperature extreme on the final cycle, measure Insulation Resistance per MIL-STD-202, Method 302, Test Condition A. On completion of Temperature Cycling each relay should be cycled for a minimum of 10,000 cycles; 5000 cycles should be run at the specified low operating temperature extreme and 5000 cycles should be run at the specified high operating temperature extreme. The cycling rate should be from 15 to 60 Hz. The contacts should be monitored for misses and there should be no misses during the 10,000 cycles of operation.

   On completion of the 5000 cycles of operation, and while stabilized at each temperature extreme, Contact Resistance, Pickup Voltage (Operate Ampere Turns), Operate Time, Dropout Voltage (Release Ampere Turns), and Release Time measurements should be made.

3. Seal — MIL-STD-202, METHOD 112, TEST CONDITION C, PROCEDURE IIIa or b (ref 2)

4. ELECTRICAL CHARACTERISTICS

   Coil Resistance MIL-STD-202, Method 303 (ref 2)

   Pickup and Dropout Voltage (Operate and Release Ampere Turns) MIL-R-5757 (ref 30)

   Static Contact Resistance MIL-STD-202 Method 307 (ref 2)

   Insulation Resistance MIL-STD-202, Method 302, Test Condition A

   Dielectric Withstanding Voltage MIL-STD-202, Method 301, Sea Level 5 to 10 seconds

   Operate and Release Time MIL-R-5757 (ref 30)

5. PRECAP VISUAL

   Precap visual is suggested in those cases where problems occur due to manufacturing processes or handling. In this case it should include careful 10 to 30 power magnification microscope visual examination of the individual reed switch capsules before they are encapsulated and prior to sealing the outer enclosure of the relay.

REED RELAYS

DESIGN AND PRODUCTION CONSIDERATIONS

Contamination. Control of manufacturing processes and cleanliness during the manufacturing of reed relays is required to assure a clean reliable product. Assembly operations, particularly prior to hermetically sealing of the reeds in glass capsules, must be performed under semiclean room conditions, with use of lint-free garments, filtered air conditioning, special shoe covers, laminar flow benches, and with smoking and eating prohibited in these clean assembly areas.

Contamination is the primary concern since it is the major contributor to relay failures. Careful control and minimizing of the contamination sources (some of which are listed below) is mandatory.

Hair, lanolin, dandruff, moisture

Metallic particles

Corrosive chemicals from plating, soldering, and cleaning

Nonconductive particles, airborne fibers, plastics, and ceramics

Film deposits from heat treating, plating, cleaning, handling

Hermetic Seal. If contamination sources are carefully controlled up to the point where the reed switch capsule is hermetically sealed, then the integrity of the hermetic seal prevents contact contamination at the contact interfaces. To assure seal integrity, fine and gross leak testing is performed, followed by 10 to 30 power microscopic visual of each reed switch capsule just prior to and just after installation in the relay assembly is required. Each reed switch capsule must be handled with care to prevent application of any stress to the leads prior to or during installation into the relay assembly.

REED RELAYS

FAILURE ANALYSIS TECHNIQUES

Predominant Failures. Failures of reed relays most frequently result from problems associated with contamination affecting contact performance or hampering movement of reeds.

CAUTION

EXTREME CARE SHOULD BE EXERCISED TO AVOID INTRODUCING CONTAMINATION INTO THE RELAY.

Opening Techniques. X-ray photograph one view of each of three perpendicular axes and examine each photograph carefully for familiarization of internal reed orientation. Cut metal housing around periphery approximately 1/16 inch above header to a depth approximately 90 percent of the metal housing thickness using an aluminum oxide cutting wheel mounted in table saw fashion.

After completion of cut, vacuum clean entire relay surface thoroughly in cleanroom environment.

Use a sharp, knife-edged tool to carefully cut through the housing material remaining from the previous cut.

Remove metal housing carefully, then remove potting as required to expose the defective reed relay leads and capsule at each end. Examine visually in detail, using a 10 to 30 power microscope, all exposed lead and capsule areas. Photograph, as required, any anomalies detected. If defect is not readily apparent, carefully remove defective reed switch capsule taking extreme care that stress is not applied to the switch glass enclosure through the leads during removal.

Failure Analysis Flow. The failure analysis flow (Figure 10-4) provides for maximum nondestructive evaluation of the failed part prior to the opening operation.

Relationship to Failures. Where it is relevant, each step of the failure analysis procedure (Figure 10-4) is related to one of the four major problem areas and their cause by a coding system which is defined on the foldout in the Appendix. Thus, one experiencing a specific type of failure can identify those steps in the failure analysis most likely to reveal the problem.

TEST/EXAMINATION	PROCEDURE	WHEN FAILURE IS / LOOK FOR: RELATED PROBLEM CODE (see foldout in the Appendix) FAIL MAKE/BREAK I	SHORT II	PAR DEV III	MECH ANOM IV
NONDESTRUCTIVE MECHANICAL					
External Visual Examination	Note all identifying markings and external damage	A, I, J	A	A, I, J	
Radiographic Inspection	If fixed focus X-ray is used, photograph in three planes mutually perpendicular to vertical axis. Examine and photograph anomalies as observed.	A, I, J	A	A	
PROBLEM AREA VERIFICATION					
NONDESTRUCTIVE ELECTRICAL					
Functional Testing	All specified electrical parameters. Record data				
Seal Test.	Helium mass spectrometer for relays having helium tracer. Those having nitrogen must be tested by Radiflow	A	A	A	
INDUCING FAILURES					
Special Conditioning	Baking, temperature cycling, vibration, and shock as required to confirm problem area				
Radiographic Inspection	Fixed focus or Vidicon as appropriate	A			
Functional Testing	All specified parameters. Record data				
PROBLEM CAUSE VERIFICATION					
Gas Analysis	Gas chromatograph. Do only if high contact resistance is encountered	A	A	A, H	
Case Removal	See paragraph "Opening Techniques". Inspect for contamination, corrosion, weld spatter, misalignment, binding, broken or fused parts, etc. Use normal and black light.	A, E, I, J	A, B,	A, C, F, G	B, E,
Function Operation and Testing	Remeasure electrical parameters. Observe contacts and mechanism for signs of binding, sticking, or hang-up while relay is operating	A		A, C	E
Solvent Rinse, Particle Isolation and Identification	Clean with Freon TF in a chemically clean container. Evaporate and identify particles. (Infrared spectrophotometry, electron beam microprobe, emission spectroscopy, etc.)	A	A	A	
Progressive Disassembly and Inspection	Carefully disassemble mechanism, inspecting each portion for wear, corrosion, galling, plating defects, contaminants, etc.	A, E, J	A	A, C, D, G	B, E

Figure 10-4. Reed Relays - Typical Failure Analysis Flow with Related Problem Codes

ALERT SUMMARIES

Summaries of ALERT reports issued against Armature, Reed, and Miscellaneous Relays are shown below. They are listed according to the Problem Area - most frequent to least frequent occurrences, except Miscellaneous are listed by type. The "ALERT ITEM NO." (first column) references each summary back to the "Problem Area/Cause, and Suggested Action" table.

ARMATURE RELAYS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
1 MSFC-68-25	FAILURE OF CONTACTS TO MAKE Contamination - between pole piece and armature	Relay failed to transfer when energized during vehicle checkout.	Failure analysis revealed numerous small pure iron particles on the armature. Particles between the pole piece and armature prevented full armature travel. Contamination came from an external source.
2 E9-70-01	FAILURE OF CONTACTS TO MAKE Contamination - between pole piece and armature	Two relays would not transfer or the contacts would not make during black-box electrical test.	Failure analysis verified the failure was caused by particulate contamination identified as magnetic weld splatter found lodged between armature and pole piece.
3 GSFC 7-28-67	FAILURE OF CONTACTS TO MAKE Contamination - between pole piece and armature	Relay failed to transfer when energized.	Metallic slivers in the magnetic gap prevented closure of armature. Slivers were caused by interference fit between header and can which sheared slivers from the header during assembly.
4 LeRC 2-14-66	FAILURE OF CONTACTS TO MAKE Contamination - between contacts	Relay exhibited intermittent operation.	Failure analysis revealed that relay failed to close because of particles which had dislodged from a cracked ceramic getter. Further examination of numerous relays selected at random from manufacturer's stock confirmed the problem of cracked getters.
5 GSFC-70-07	FAILURE OF CONTACTS TO MAKE Contamination - between contacts	Three relays exhibited open circuit contacts.	Failure analysis revealed contamination in the form of solder flux, nonconductive fibers, and organic particles. An all welded construction replacement lot was inspected and rejected because of flaked copper plating on the actuator arms. A second replacement lot was fabricated, inspected, accepted, and sealed. This lot was screened by the manufacturer and failed vibration test because of low armature return spring force.
6 MSFC-76-03	FAILURE OF CONTACTS TO MAKE Contamination - between contacts	Normally closed contacts showed no continuity.	Investigation revealed that the failures occurred because of Teflon pieces contaminating the relay contacts causing a break in the circuit. Teflon spacers are used to insure insulation resistance.

ARMATURE RELAYS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
14 K9-69-01	FAILURE OF CONTACTS TO BREAK Contamination - solder flux on contacts	During vibration testing a rotary armature hang-up (failure to release) occurred when relay was de-energized.	It was determined that the armature was binding on the core, causing the failure. Investigations revealed that the hang-up was caused by misdrilling of the core bearing hole. The concentricity of the armature shaft and recess was out of tolerance and was contributing to the hang-up.
15 GSFC-68-07	FAILURE OF CONTACTS TO BREAK Contamination - solder flux on contacts	Sticking and open contacts experienced randomly over the past six months.	Four relays were observed to have solder flux within them. These relays passed acceptance tests and operated in system bench tests. The solder flux eventually caused the relays to fail because of sticking and/or high resistance contacts.
16 R6-71-01	FAILURE OF CONTACTS TO BREAK Armature binding	Relays failed in card test after an average of 200 cycles.	Failure Analysis revealed an intermetallic galling between the armature and return spring. Galling was the result of low moisture content within the relay caused by a malfunctioning gas dryer. Moisture acts as natural lubricant between metal surfaces.
17 MSFC-68-13, 13A, 13B	FAILURE OF CONTACTS TO BREAK Armature binding	Relay failed to transfer to normal state when de-energized during functional tests.	X-rays revealed that the contact actuator arm was touching the relay case. Only when a slight pressure was applied to the end of the relay case, did the relay hang up in the energized position.
18 MSFC-67-01 Add 1, 2	SHORT Contamination - between contacts	During reliability testing, simulation of an engine shut down condition induced closure of open contacts in several relays.	Internal examination revealed metallic particles and slivers, solder splash and balls, weld splash and balls, nylon/teflon particles and strings, bristle or hair, and an unidentified white powder. Investigation at manufacturer's plant indicated that all relays were contaminated with metallic and nonmetallic particles.
19. MSFC-68-18	SHORT Contamination - between contacts	Three relays from three separate lots containing a total of 112 relays failed random vibration acceptance testing.	Failure analysis revealed solder balls in each relay. Verified source of contamination was the remelting of solder.
20 MSFC-67-06	SHORT Contamination - between contacts	Loose solder plugs in relay cans.	The production process requires a solder plug to be placed in the purge port to facilitate soldering. Accumulated tolerances made it possible for some plugs to fall through the port. Internal clearances of the relay will allow the plug to travel and cause shorts or blocking of operation.

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REED RELAYS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
28 KSC 7-7-66	ELECTRICAL PARAMETER DEVIATION - HIGH CONTACT RESISTANCE Loss of mercury	Low meter readings were obtained during functional test. The trouble was traced to increased contact resistance. X-ray examination showed evidence of mercury spillage.	Failure analysis revealed epoxy potting material adhering to the capsule. As the epoxy set, stress caused the glass to crack and mercury to spill. Without mercury to wet the contacts, the contact resistance increased.

MISCELLANEOUS RELAYS

TYPE; ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
CHOPPER 29 KSC-69-16	ELECTRICAL PARAMETER DEVIATION - HIGH CONTACT RESISTANCE Unstable epoxy compound.	Five failures occurred in fifteen recorders.	Problem was caused by a particular batch of unstable epoxy compound which allowed parameter shift after about six months.
PHASE SEQUENCE 30 KSC 3-2-66	FAILURE OF CONTACTS TO MAKE Actuator arm fell off	During system check-out, the relay used to indicate correct phasing of an inverter failed to have an output even though the motor was running.	Failure analysis revealed that the contact actuating arm had fallen off because of the loosening of the motor-torque-arm set screw. No locking provision exists for the screw, nor is there a seating flat on the shaft. In a "base-down" condition, the unsecured arm can fall on the energized headers in the relay and short the power supply
THERMAL TIME DELAY 31 MSFC-65-06	ELECTRICAL PARAMETER DEVIATION - EXCESSIVE TIME DELAY Low heater coil resistance	Thermal time delay relay exhibited excessive time delay for actuation	Investigation revealed that the relay malfunctioned because of change in resistance of the heater element. The heater element was removed and microscopic examination of the heater coil indicated poor insulation of the wire used in the coil.
TIME DELAY 32 C6-68-01	ELECTRICAL PARAMETER DEVIATION - INADEQUATE TIME DELAY Contamination - aluminum particles	Two relays timed out too quickly.	Contamination of aluminum particles between the nylon timing disk and the mating relay surface provided air leakage paths from the timing bellows other than the normal timing path. Source of the contamination was concluded to be from the aluminum body under the timing disk.

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SECTION 11
RESISTORS
(GIDEP CODE 651, 661)

11

INTRODUCTION

OBJECTIVE

The objective of this section is to identify the major problem areas associated with the use of resistors and to suggest approaches (developed from experience) for dealing with these problems.

SECTION ORGANIZATION

The resistor section is presented with the following organization:

General

1. Basic failure problems associated with resistors are identified based upon ALERT and industry experience.

2. Where applicable, a screening technique is suggested for detecting finished parts having a potential for failure.

Subtopics Treatment of Specific Types

1. Resistor type background.

2. For those in the process of selecting parts and manufacturers, or attempting to eliminate part problems at the manufacturer levels, a portion is devoted to describing the inner construction of selected types and describing the manufacturing sequence necessary to produce the part. Particular emphasis is given to the design or manufacturing deficiencies associated with the identified failure mechanisms.

3. Basic approaches are provided to assist in developing a competent failure analysis plan where corrective action at the part level is desired. The material is arranged so that one experiencing a specific problem can identify those steps in the failure analysis process likely to reveal that problem.

Resistor Types. Resistors have been divided into subtopics according to their internal construction. Metal and carbon film, variable, wirewound, and carbon composition resistors have been discussed in depth. Other types of resistors include only summaries of ALERT reports.

RESISTOR FUNDAMENTALS

What a Resistor Should Do. Resistance is a basic electrical circuit parameter having properties which result in the dissipation of electrical energy ($R = P/I^2$). Resistors are devices constructed to provide known amounts of resistance to circuits in order to fulfill electrical design requirements. In its fundamental form, a resistor is a device made of a material having atomic properties such that practical design variations can produce a useful resistance range (e.g., 1 to 1,000,000 ohms). Its resistance is directly proportional to the specific resistance and length of the material, and inversely proportional to the cross sectional area of the material. The specific resistivity of a material is determined empirically by relating it to that constant associated with silver.

Practical Considerations. Analysis indicates, that because of physical imperfections in materials and laws that govern their properties, a resistor cannot be defined by its resistance value alone. Physical considerations force us to recognize such compromising characteristics built into a resistor as voltage and current limitation, frequency effects, and temperature coefficient of resistance. It is only by recognizing and controlling all of these factors that stable reliable resistors can be developed and manufactured. All of these characteristics are inherent limitations associated with the materials and processes used in the fabrication of the resistors and are normally dealt with as design limitations.

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PROBLEM/SCREENING SUMMARY

Scope. This summation is an accumulation of knowledge and experience gained in dealing with resistor failures and in avoiding those failures. It addresses itself to the causes and effects of failures, and shows the suggested screens that will allow identification of resistors having latent or incipient defects.

This summary is aimed toward identifying resistor problem areas and failure causes. Having identified problems, and recognizing that the typical user is concerned with eliminating this problem from a group of resistors on hand, suggestions are made for performing screening. These screening suggestions are based primarily upon industry experience. The problem areas have been grouped under the basic categories of open, short, parameter deviation, and mechanical anomaly.

ALERT Item No. Where directly applicable, the "ALERT Item No." of the ALERT report describing a specific cause for a failure is listed against that cause. Thereby, a cross reference is provided between a specific failure cause found in the "ALERT Summaries" and the broader failure experience/avoidance knowledge shown in this presentation.

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VARIABLE RESISTORS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
OPEN Contamination	13,14	DC Resistance, Burn-In, Temperature Cycling, DC Resistance, Peak Noise, and Continuity
OPEN Inadequate contact	15,16,17, 18	DC Resistance, Temperature Cycling, DC Resistance, Peak Noise, and Continuity
OPEN Inadequate solder connection	19	DC Resistance (total), Temperature Cycling, DC Resistance, and Peak Noise
OPEN Broken contact spring Lead separation	 20 14,21	DC Resistance (total), Temperature Cycling, DC Resistance (total), Peak Noise, and Continuity
SHORT Contamination	22	DC Resistance, Temperature Cycling, DC Resistance, Peak Noise, and Continuity
ELECTRICAL PARAMETER DEVIATION - OUT OF TOLERANCE Contamination	23	DC Resistance, Burn-In, Temperature Cycling, DC Resistance, Peak Noise, and Continuity
ELECTRICAL PARAMETER DEVIATION - OUT OF TOLERANCE Excessive electrical noise	24	Invoke limited life requirements on components which rely on electrical continuity through a lubricant on sliding contacts
MECHANICAL ANOMALY - BROKEN SCREWHEADS Poor epoxy bond	25	Visual Examination at 10X
MECHANICAL ANOMALY - LOSS OF WIPING ACTION Canted shaft	26	DC Resistance, Temperature Cycling, DC Resistance, Peak Noise, Continuity, and Visual Examination
MECHANICAL ANOMALY - LOSS OF WIPING ACTION Faulty drive gear Contamination	 27,28,29 30	DC Resistance, Peak Noise, and Continuity

WIREWOUND RESISTORS

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION - SCREEN (see "Screening Inspections and Tests")
OPEN Broken resistor element wire	31,32,33	DC Resistance, Short-Time Overload, Temperature Cycling, and DC Resistance
OPEN Broken resistor element wire	34	Terminal Twist Test, MIL-R-39005, (ref 31)
OPEN Broken resistive element wire	35	None. Manufacturer has implemented inspection tests to prevent acceptance of wire with cracks in the insulation

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SCREENING INSPECTIONS AND TESTS

Basic Screening. The screening inspections and tests suggested for resistors included in the Problem/Screening Summary are as follows:

1. Temperature Cycling
2. Burn-In; sometimes called "voltage conditioning," "voltage aging," or "voltage stabilization"
3. Seal Test (for hermetic devices)
4. Electrical Measurements
5. Visual Examination
6. Radiographic Inspection (for devices with opaque cases)
7. Short-Time Overload
8. Tap Test (metal film resistors only)
9. Peak Noise and Continuity (variable resistors only)

Objective. The purpose of the screening is to allow detection of parts that: (1) have been improperly processed by the manufacturer, (2) contain flaws or weak spots in the resistance element, (3) have poor solder or weld connections, or (4) have any other anomalies that could result in a failure under normal conditions.

Additional Screening. In cases where specific characteristics are critical in the function of the using equipment, e.g., temperature coefficient, such critical parameters should be added to the requirements of these screening tests.

Envelope Removal/Dissection. The basic approach taken here is to subject each of the devices to a test procedure in order to make a one-by-one acceptance determination. The disadvantage of this approach is the underlying assumption that the internal construction materials, processes, etc. from part-to-part are homogeneous so that the devices can be treated as a uniform lot. If the devices are not produced under similar design criteria and manufacturing controls which permit a heterogeneous lot to exist, a single screening procedure may not be the optimum for all units. For this reason, it is frequently desirable to examine the internal design and construction. This is accomplished, first, by a nondestructive radiographic inspection; and second, by performing a destructive envelope removal or dissection on a limited sample of devices. This procedure is more meaningful if a design/construction baseline has been established as a comparison criterion.

1. TEMPERATURE CYCLING — MIL STD 202, METHOD 102 (5 cycles) (ref 2)

   General. This environmental exposure will assist in detecting a variety of design and manufacturing deficiencies resulting from materials with incompatible temperature coefficients of expansion, inadequately bonded materials, and materials with improper chemical composition.

   Complementary Tests. Seal test and electrical measurements will detect degradation and catastrophic failure resulting from the temperature cycling exposure. Resistance (or DC Leakage) is the suggested electrical measurement to be performed after Temperature Cycling and Seal Test; test condition selected must be compatible with the part characteristic.

2. BURN-IN

   Burn-In typically consists of the application of rated power (not to exceed maximum rated voltage) at the maximum rated wattage-temperature for a period of time associated with the resistor type and resistance material. The purpose is to stress the resistor electrically and thermally to the maximum of its designed operating capability. Experience has indicated that this type of stress is extremely effective in detecting incipient failures. The number of hours that a part is burned in has evolved as a result of experience. This time is based on minimizing the infant mortality rate of a specific part type. A typical burn-in time is 100 hours.

is varied by uniform rotation of the lead screw. The deviations from a linear increase/decrease are observed on an oscilloscope and recorded as noise and/or open. It should be remembered that open conditions detected in this manner may be caused by contamination on the surface of the resistance element as well as actual discontinuities in the resistance element.

10. ENVELOPE REMOVAL/DISSECTION

A sample from each lot (e.g., lot-date-code) has its envelope removed and/or is dissected in order to detect internal anomalies such as part damage, poor workmanship, improper materials, etc. It is suggested that a sample base line dissected part be used as a standard for comparison.

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DESIGN AND PRODUCTION CONSIDERATIONS

General. Typical metal or carbon film, variable, wirewound, and carbon composition resistors (Figures 11-1, 11-2, 11-3 and 11-4) and typical assembly flows (Figures 11-5, 11-6, 11-7, and 11-8) are presented together with the suggested controls required to assure a reliable product.

Assembly Flow. The manufacturing flow of a resistor is essentially the same for all manufacturers, differing principally in the degree of process controls, number of production tests, and extent of automation. The assembly flow as described is typical of what may be expected for resistors of the type illustrated. Significant variables are listed on the typical flow diagram with those operations that are considered critical for the design of a reliable resistor. In-process inspection and testing may vary from one manufacturer to another depending on the sizes of the lots produced and the degree of automation.

TYPICAL METAL OR CARBON FILM RESISTOR DESIGN (Figure 11-1)

ITEM	ITEM NAME	MATERIAL OF CONSTRUCTION
1	Lead	Gold plated nickel
2	End Fillet	Copper-silver alloy
3	End Cap	Nickel-iron alloy such as Kovar, Rodar, etc.
4	Core	Ceramic or glass
5 5	Metal Film or Carbon Film	Nickel-chromium resistance alloy or Carbon
6	Envelope	Ceramic or glass
7	End Disk	Nickel-iron alloy
8	Spiral	Cut through metal film that exposes core
9	Envelope Gas (not shown)	Dry gas/air mixture
10	Varnish (not shown)	Hi-temperature varnish over resistor body (optional)

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TYPICAL VARIABLE RESISTOR DESIGN (Figure 11-2)

ITEM	ITEM NAME	MATERIAL OF CONSTRUCTION
1	Cover	Moldable plastic such as dialyll phthalate
2	Contact Spring	Pt-Pd-Au alloy
3	Worm	Stainless steel
4	Case	Moldable plastic such as dialyll phthalate
5	O-Ring	Silicone rubber
6	Retaining Pin	Nylon
7	Collector Ring	Beryllium copper
8	Gear	Nylon
9	Mandrel	ML magnet wire
10	Element Resistance Wire	Nickel-chromium alloy
11	Varnish	Hi-temp varnish
12	Pin	Gold plated nickel
13	Tab	Silver plated copper
14	Spot Weld	
15	Element Preform	Adhesive film

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TYPICAL WIREWOUND RESISTOR DESIGN (Figure 11-3)

ITEM	ITEM NAME	MATERIAL OF CONSTRUCTION
1	Lead	Gold plated nickel
2	Weld Tab	Gold plated nickel
3, 8	Bobbin	Rigid plastic such as dialyll phthalate
4	Cushion Coat	Silicon rubber
5	Wire	Nickel-chromium resistance wire
6	Shell	Rigid plastic such as dialyll phthalate
7	Cap	Gold plated nickel
9	End Cap	Moldable plastic
10	Insulating Tape (not shown)	Teflon

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TYPICAL CARBON COMPOSITION RESISTOR DESIGN (Figure 11-4)

ITEM	ITEM NAME	MATERIAL OF CONSTRUCTION
1	Lead	ETP copper with tinned coating
2	Shell	Phenol/formaldehyde system resin filled with microcrystalline silica
3	Core	Phenol/formaldehyde system resin filled with microcrystalline silica and carbon. (Note: Carbon is either calcined carbon black or graphite)
4	Lead header	Phenolic based conductive paint
5	Impregnant	Halogenated aromatic compounds

Note: Item 5 is not shown on drawing — will be found on outer surface and within shell (2) and/or core (3).

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ASSEMBLY FLOW

General. A review of the following assembly flow diagrams (Figures 11-5, 11-6, 11-7 and 11-8) for the four significant types of resistors will reveal that no truly proprietary processes are used. The only significant variation that will be found, based on industry experience, is the process variations found in depositing the film used in film resistors such as the variation in the substrate material used and the composition of the films. An examination of the implementation of the process inspection requirements and process control documents gives an indication of quality being built into the parts but not necessarily an indication of good quality.

Problem Areas for Film Resistors. The areas in processing of film resistors that are of significant concern are those processes that can induce fracture of the core and control of envelope gas content. Fracture of the core is an insidious failure mechanism as it can result in intermittent opens or parameter deviations. Inclusion of excessive hydrogen and/or moisture in the envelope gas can lead to a time-dependent parameter drift that may or may not be radically changed by heating, either by baking or application of short-time overload.

Problem Areas for Variable Resistors. The predominant cause of variable resistor failures because of processing faults is inclusion of contaminants. The contaminants vary from extrusion of improperly cured setting-bed varnish to assorted debris, all of which generally result in erratic open conditions.

Problem Areas for Wirewound Resistors. The significant processing problem area for wirewound resistors is faulty connections, such as inadequate weld of the resistance element wire to termination tab and damaged insulation that has been abraded during the winding process. The faulty connections are more commonly observed as opens at either high or low temperatures. The loss of resistance element wire insulation results in parameter changes and/or shorts.

Problem Areas for Carbon Composition Resistors. The problem areas associated with carbon composition resistors are more theoretical than actual. Catastrophic failures, open or short, are almost nonexistent. However, as with any assembly that requires several steps, problems can appear as listed in the flow diagram. Since people usually create problems associated with part problems, the automation/mechanization in making composition resistors is the highest of any resistor in this section.

Insuring Reliability. It is because of the above considerations that special part requirements become necessary where these devices are used in long-life and critical applications. They include: (1) lot rejection because of excessive screening fallout, (2) failure analysis by the manufacturer of catastrophic screening failures, and (3) user receiving inspection and envelope removal.

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FLOW DIAGRAM			RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL	MANUFACTURING OPERATION	CRITICAL PROCESS	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
Mandrel (9) Element Wire (10) Varnish (11)	Wind, helix, and saw	Spacing of element wire and cure of varnish	A, D	C	B3	
	Flatten element		A	A	B3	
Tab (13)	Braze tab to element and clean	Braze time, temperature, and atmosphere	H	A		
Case (4) Collector Ring (7) Pins (12)	Spotweld collector to case assembly	Weld process parameters	H			
Element Preform (15)	Attach element	Attaching process parameters	A			
(14)	Spotweld tab to pins	Weld process parameters	A			
Cover (1) Contact Spring (2) Gear (8)	Lubricate element; add gear, spring and cover; and seal	Contaminant introduction	C, D	C	A2	
O-Ring (5) Worm (3)	Install O-ring and worm	Contaminant introduction	C, D	C		
Plug	Drill plug hole and inject		C, D			
	Screening and test					
	Label, pack, and ship					

NOTE: For items 1 through 15 see Figure 11-2.

Figure 11-6. Variable Resistor - Typical Assembly Flow with Related Problem Codes

FLOW DIAGRAM				RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL		MANUFACTURING OPERATION	CRITICAL PROCESS	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
Shell	2	Mix shell material	Material control	C	C		C
Lead	1	Mold shell with one lead	Pressure, time, and temperature	E	C		
Core	3	Mix core material and insert	Material control	C	C	A1	
Lead	1	Add other lead	Alignment	E	C	A1	D
		Compress	Prevention of body fracture	A		A4	D
		Cure	Pressure, time, and temperature				
Impregnate	5	Vacuum impregnate	Coverage		C	A1	C
		Degrease		A	C		D
		Acceptance test					
		Sort, label, final inspection and ship					

NOTE: For items 1 through 4 see Figure 11-4.

Figure 11-8. Carbon Composition Resistor - Typical Assembly Flow with Related Problem Codes

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TEST/EXAMINATION	PROCEDURE	WHEN FAILURE IS / LOOK FOR: RELATED PROBLEM CODES (see foldout in the Appendix) OPEN I	SHORT II	PAR DEV III	MECH ANOM IV	APPLICABLE RESISTOR TYPE MF	CF	VAR	WW	CC
NONDESTRUCTIVE MECHANICAL										
External Visual Examination	Record all identifying markings and external damage (photographs preferred)			A2	A thru E	X	X	X	X	X
Radiographic Inspection	If fixed focus X-ray is used, photograph in two mutually orthogonal planes as required to record any interior anomalies. If Vidicon (imaging) is used, examine and record anomalies as observed	A, C, E, H, I	A	A3		X	X	X	X	
PROBLEM AREA VERIFICATION										
NONDESTRUCTIVE ELECTRICAL										
Resistance Confirmation	Measure and record resistance at applicable temperatures (room ambient and specification limits for high and low)	all	all	all		X	X	X	X	X
Continuity Evaluation	Measure and record peak noise and continuity	A,C,D	A, C	A1; B3				X		
Ceramic Fracture Evaluation	Tap test and record maximum resistance deviation (Note: This is a comparative evaluation and results should be compared with results obtained from known good devices tested under identical conditions)	B				X	X			
Hermeticity Evaluation	Perform leak test per MIL-STD-202, Method 112, Condition "A" and "C," and record observations	F, G	B	A2; B1		X	X			
Resistance Confirmation	Repeat resistance measurement at applicable temperatures and record any changes in values	all	all	all		X	X	X	X	X
INDUCING FAILURES										
Conditioning	Baking, vibration, thermal cycling, and short-time overload only if required to confirm problem area					X	X	X	X	X
Parameter Verification	Repeat resistance measurement, peak noise, and continuity as applicable and record any observed changes					X	X	X	X	X

Figure 11-9. Resistor - Typical Failure Analysis Flow with Related Problem Codes

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ALERT SUMMARIES

Summaries of ALERT reports issued against Metal Film, Carbon Film, Wirewound, Variable, and Miscellaneous Resistors are shown below. They are listed according to the Problem Area-most frequent to least frequent occurrences, except the Miscellaneous are listed by type. The "ALERT ITEM NO." (first column) references each summary back to the "Problem Area/Cause, and Suggested Action" table.

METAL FILM RESISTORS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
1 GSFC-70-09	OPEN Broken resistive element ELECTRICAL PARAMETER DEVIATION - OUT OF TOLERANCE Incorrect material	Two resistors purchased in an unfinished form and then trimmed and encapsulated, failed.	Failure analysis by the manufacturer revealed that a substitute isolation coat material caused resistance instability in one resistor. The main element of the other resistor had been cut (accidentally) during the trimming operation.
2 GSFC 7-18-67	OPEN Fractured substrate	Resistor failed open during bench tests, after thermal cycling and removal from storage.	Glass substrates fractured without cracking the epoxy encapsulant. Broken substrates may remain in position and maintain normal electrical continuity until mechanically or thermally exercised.
3 MSFC-65-07	OPEN (Intermittent)[1] Fractured ceramic core	Resistors failed open/intermittent open during temperature cycling.	Failure analysis revealed that the ceramic cores were cracked beneath the end cap. Investigation by the manufacturer indicated that because the capping operation was out of control, excessive stress was created in the core beneath the end cap.
4 K9-72-11	OPEN Dissolved film	Resistors failed open following humidity test.	Microscopic examination, after removal of conformal coating, revealed missing metal film. Failure is typical of that occurring in this resistor type when moisture penetrates the protective coating and reacts with contaminants and the metal film, resulting in electrolysis which in effect etches away or dissolves the metal film.
5 GSFC 3-18-66	SHORT Silver migration	Three resistors exhibited a sudden decrease in resistance.	Investigation revealed silver substance in the inner cavity of the failed units. In a controlled series of tests, attempting to simulate the failure, five resistors failed after temperature humidity cycling. Two of these were confirmed to have developed an internal path because of silver migration.

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CARBON FILM RESISTORS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
11 M3-70-02	OPEN Broken ribbon lead	Resistor failed open during temperature cycling.	Failure analysis revealed that solder had flowed up the ribbon lead from the PC Board to the chip (the lead is soldered to the PC Board on which the chips are mounted). The resulting lack of stress relief on the lead caused the ribbon to break.
12 GSFC-68-02	OPEN Corona discharge	Corona discharge in the hollow core ceramic tube between ends of the terminal connections after being in vacuum for 24 to 36 hours.	Corona discharge caused by gas trapped during assembly of the resistor. Gas gradually leaked out until discharge pressure was reached.

VARIABLE RESISTORS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
13 M3-70-01	OPEN Contamination	Devices failed intermittently open during system level tests.	Contamination on the coil caused intermittent opens as the rotor passed over the winding.
14 K9-71-12	OPEN Contamination Lead separation	Of 20 units tested, 18 had open end terminals and 1 had erratic operation.	Investigation revealed a gap between the end terminals and the silver epoxy. The erratic operating unit had a plastic material on the resistive element.
15 L9-69-01	OPEN Inadequate contact	Mechanical adjustment of potentiometer caused intermittent operation.	Failure analysis revealed intermittent electrical contact of the center shaft to the end shaft terminating joint.
16 B1-A-72-01	OPEN Inadequate contact	Resistors demonstrated intermittent opens.	Investigation showed that the intermittent condition was due to a loose center terminal (collector) that caused the wiper to have an unpredictable travel. The epoxy bond between terminal and housing was inadequate.
17 LeRC-69-02	OPEN Inadequate contact	A potentiometer slider opened during temperature cycling of signal conditioner.	Failure analysis revealed a broken flat contact spring on the slider.
18 MSC-71-05, 05A	OPEN Inadequate contact	Five potentiometers failed during evaluation test.	Failure analysis attributed the failures to a minor wear problem. Investigation by the manufacturer revealed the primary cause of the failure was the improper shape of the wiper contacts which severed the resistance film.

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VARIABLE RESISTORS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
27 MSFC 11-13-67	MECHANICAL DAMAGE - LOSS OF WIPING ACTION Faulty drive gear	Loss of wiper adjustment.	Not specified. ALERT number KSC-67-69 specifies the same problem.
28 KSC-67-68	MECHANICAL DAMAGE - LOSS OF WIPING ACTION Faulty drive gear	Loss of wiper adjustment capability is possible.	Eccentricity in the plastic main drive gear causes the wiper to hang-up in the stop. Cause of the problem was traced to a defective 8-cavity mold used for casting the gear.
29 KSC-67-69	MECHANICAL DAMAGE - LOSS OF WIPING ACTION Faulty drive gear	Loss of wiper adjustment	Loss of wiper adjustment because of eccentricity between drive gear and resistor interior.
30 F3-A-72-06	MECHANICAL ANOMALY - LOSS OF WIPING ACTION Contamination	Resistance was found to be nonadjustable after potting.	Failure analysis disclosed potting compound inside the resistor case. Entrance of the compound was traced to a void (hole) in the molded resistor case.

WIREWOUND RESISTORS

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
31 MSC 1-25-66	OPEN Broken resistor element wire	During test of an earth landing system, a power supply experienced failure of resistors.	The method of potting used by the manufacturer was inadequate. Resistor element wire which is unsupported by potting because of voids, especially at attachment to the lead wire, is susceptible to failure from vibration and/or movement of the lead wires.
32 GSFC 9-20-67	OPEN Broken resistor element wire	Unsatisfactory circuit design test results were traced to open resistors.	Failure analysis revealed breaks in the resistance wires at their connection to the resistor lead. Breaks were caused by improperly centered bobbin within the tubular epoxy case. This resulted in inadequate isolation of resistance wires from externally applied stresses and leads were bent too close to resistor body during assembly into circuit.
33 SH-71-01, 01A	OPEN Broken resistor element wire	Resistors overheated and blew the resistance element from the aluminum housing during equipment test.	Failure analysis revealed aluminum particles had shorted the resistor to the chassis. The aluminum had been scraped off (from an improperly bored chassis extrusion) when the resistor element was inserted into the housing.

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MISCELLANEOUS RESISTORS

Type; ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
SENSISTOR 41 MSFC-67-09	OPEN Poor lead welds, cracked tabs, cracked resistive elements	Devices exhibited intermittent opens during temperature cycling	Investigation revealed weakness in three areas: 1) poor lead to transfer tab weld 2) cracked or torn transfer tabs 3) cracked silicon resistive element

NOTE:
1. Where no ALERT number (GIDEP) exists, the originator and data are shown.

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SECTION 12
SWITCHES
(GIDEP CODE 791)

12

INTRODUCTION

OBJECTIVE

The objective of this section is to identify the major problem areas associated with the use of switches and to suggest approaches (developed from experience) for dealing with those problems.

SECTION ORGANIZATION

The switch section is presented with the following organization:

General

1. Basic failure problems associated with switches are identified based upon ALERT and industry experience.

2. Where applicable, a screening technique is suggested for detecting finished parts having a potential for failure.

Subtopics Treatment of Specific Types

1. Switch type background.

2. For those in the process of selecting parts and manufacturers, or attempting to eliminate part problems at the manufacturer levels, a portion is devoted to describing the inner construction of selected types and describing the manufacturing sequence necessary to produce the part. Particular emphasis is given to the design or manufacturing deficiencies associated with the identified failure mechanisms.

3. Basic approaches are provided to assist in developing a competent failure analysis plan where corrective action at the part level is desired. The material is arranged so that one experiencing a specific problem can identify those steps in the failure analysis process likely to reveal that problem.

Switch Types . Switches have been divided into subtopics according to their internal construction. This section of the publication includes a detailed discussion of the subminiature snap-action switch, and the thermostatic snap-action switch. The snap-action switch, because of the stability of its operating characteristics provided by the snap-action, is most frequently used in aerospace applications. Other subtopics such as pressure switches, transfer switches, and squib switches are included as summaries of ALERT reports.

SWITCH FUNDAMENTALS

What a Switch Should Do. A switch is a device which can be used to open or close an electrical circuit. Ideally, when open there is no current through the switch and when closed there is no voltage across it. Practically, the open circuit current is so small that the voltage across the switch is essentially the same as if the switch were not there and the closed circuit resistance is so small that the voltage drop across the switch is small compared to the open circuit voltage. This section is concerned with switches whose operation depends on the motion of electrical conductors into or out of contact in response to motion external to the device. (When the entire motion is internal to the device, the device is usually a thermostatic switch, a relay, or similar internally actuated type device.) Circuit closure may result from bridging between fixed contacts or from motion of a contact on a flexible, conducting member. The primary rating characteristics for switches is the current carrying capacity and maximum voltage which is dependent on the size of the contact surface area, contact spacing, and the materials of construction of the contacting members.

Practical Considerations. Analysis indicates that because of the physical imperfections in materials and laws that govern their properties, a switch cannot be simply defined by its current carrying capacity. Physical considerations force us to recognize such compromising characteristics built into a switch as limitations on operating forces required, mechanical stability (sensitivity to vibration caused malfunction), insulation resistance, dielectric withstanding voltage, thermal stability, and maximums for actuator (plunger) travel distances (pretravel and overtravel), and voltage maximums established by contact spacing. Mechanical stability, actuator (plunger) travel distances, current maximums, and voltage maximums are primarily a function of mechanical design of the device. Insulation resistance, dielectric withstanding voltage and thermal

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where it is necessary to have assurance that future failures will not occur, a portion of this section is devoted to describing some of the considerations involved in performing effective failure analysis.

Reliability/Life. It is anticipated that as a result of this series of actions at the part level (screening, analysis of design and manufacturing, and effective failure analysis) that significant improvement in reliability and life will be realized.

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PROBLEM AREA/CAUSE AND SUGGESTED ACTION

SWITCHES

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION SCREEN (see "Screening Inspections and Tests")
OPEN (including increased resistance)		Electrical and Mechanical Characteristics Test
Contaminated contacts	1,2,3,4,	
Insufficient contact pressure	5	
OPEN (including increased resistance)		None. Application problem in that the switch should have been sealed
Contact corrosion	6	
SHORT (including intermittents)		All screening tests listed, with emphasis on Visual Examination and Radiographic Inspection.
Conductive contamination	7	
SHORT (including intermittents)		Sinusoidal Vibration, Temperature Cycling with Run-In Test, and Electrical and Mechanical Characteristics Test
Improperly routed leads	8	
Loose contact	9	
Loose or broken conductive part	10	
PARAMETER DEVIATION - OPERATION AND RELEASE FORCE ANOMALIES		Temperature Cycling with Run-In Test, and Electrical and Mechanical Characteristics Test
Loose or defective parts	11, 12	
Contamination	13	
Sticking	14	
PARAMETER DEVIATION - OPERATING DISPLACEMENT		None. Application problem in that proper care was not used when cleaning flux from the terminals
Loose or defective parts	15	
EXTERNAL MECHANICAL ANOMALY		Visual Examination
Cracked or damaged case	16, 17	
EXTERNAL MECHANICAL ANOMALY		Electrical and Mechanical Characteristics Test, Seal Test, and Visual Examination
Defective seal	18	

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permitting the flow of large leakage currents, can disturb the operation of circuits intended to be isolated by forming feedback loops. This test is especially helpful in determining the extent to which insulating properties are affected by deteriorative forces, such as heat, moisture, oxidation, etc. It is normally preformed while the switch is stabilized at high temperature during final cycle of thermal cycling.

4. DIELECTRIC WITHSTANDING VOLTAGE — MIL-STD-202, METHOD 301 (ref 2)

The dielectric withstanding voltage test consists of application of a voltage higher than the rated voltage for a specified time between mutually insulated portions of the switch or between insulated portions and ground. This is used to prove that the switch can operate at its rated voltage and withstand momentary overpotentials caused by switching surges and other similar phenomena. It serves to determine whether insulating materials and spacings within the switch are adequate. After application of the specified overvoltage, the switch is examined for evidence of arcing, flashover, and insulation breakdown.

5. SEAL TEST (HERMETIC DEVICES ONLY)— MIL-STD-202, METHOD 112 (ref 2)

General. The purpose of this test is to verify the integrity of the hermetic seal. Typical failure areas occur where materials are fused, brazed, or soldered to make the final seal. The seal test will detect manufacturing defects, damage resulting from handling, seal failures resulting from mismatched temperature coefficient of expansion of materials, etc., which can result in the intrusion of contaminating atmospheres that result in corrosion and/or contamination.

6. ELECTRICAL AND MECHANICAL, OR TEMPERATURE CHARACTERISTIC MEASUREMENTS

These tests are designed to verify that the following switch characteristics are within specification requirements:

1. For subminiature snap-action switches: operating force, release force, pretravel, overtravel, differential travel, operating point, and contact resistance.

2. For thermostatic snap-action switches: contact opening temperature, contact closing temperature, differential, repeatability, and contact resistance.

Because of the variety of designs found in various kinds of subminiature snap-action and thermostatic snap-action switches, exact methodology for all testing will not be defined.

For testing thermostatic snap-action switches, an agitated, calibrated, uniform temperature controlled liquid type bath should be used which, in conjunction with precision quartz type instruments, will provide a ± 0.1°F temperature tolerance for over-all system accuracy. Each switch during each individual operating parameter test should be temperature cycled in the liquid bath at a constant rate of temperature change not exceeding 1°F every three minutes. The upper and lower temperature of each liquid bath temperature cycle should be a minimum of 5°F above and below the operate temperature of the thermostatic switch being tested. During each cycle the contact opening, closing, and differential temperatures should be recorded. Contact resistance should be recorded at the time of, or immediately after, each contact closure. The test employed for measurement of contact resistance is MIL-STD-202, Method 307 (ref 2). Normally, contact resistance is specified as 0.050 ohms maximum. Except in those cases where the switch is to be used for low level applications, the switch contact loading for resistance measurements is 6 ± 0.1 Vdc open circuit voltage and 0.100 ± 0.005 ampere closed circuit current. It is recommended that for those switches that are to be used in low level applications, the contact loading for all screening and testing including resistance measurements not exceed 0.030 Vdc open circuit voltage and 0.010 closed circuit current. Low level is defined in MIL-STD-202, Method 311, and in MIL-S-8805 (ref 32) as 30 millivolts maximum and 10 milliamperes maximum.

In thermostatic snap-action switches contact chatter or bounce during opening and closing of the contacts, or contact creepage, which is slight opening of the contacts as the operate temperature is approached just prior to contact transfer, are inherent in the design. The contact movements are a result of the movable contact being moved by the metallic element actuator (bimetal disk) which exhibits small displacement (motional instability) on either side of (above or below) the operate temperature just prior to disk snap. (Disk snap is defined as the maximum disk displacement at the operate temperature.)Tests have been devised to screen out those thermostatic switches that exhibit excessive contact creepage, chatter, and bounce during contact opening or closing. One test method is performed by applying a dc voltage of sufficient amplitude to generate a sustaining arc for a given contact gap. Current is limited to the microampere level through the contacts during this test to minimize contact surface burn at the point where the contacts meet. A time limit is set for the arc duration during opening or closing of the contacts, and those switches failing to meet the time limit are rejected and removed from the lot.

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SUBMINIATURE SNAP-ACTION SWITCHES

CHARACTERISTICS

General Considerations. As was discussed previously, switches are electromechanical devices that interrupt/restore the flow of current in a circuit in response to external mechanical stimuli. The interruption/restoration function is accomplished by mechanically moving a conductive member to bridge between two or more contacts. Degradation of the surfaces of the contacts and/or application of excessive transient mechanical forces can degrade or cause false operation of the installed switch. Not to be overlooked in any discussion of operational limits for switches are the insidious atmospheric effects such as explosions caused by ambient gases, arcing because of low atmospheric pressure, etc., generally associated with nonhermetic switches.

Atmospheric Effects. The nonbenign effects of atmospheric environment on nonhermetic switches can be divided into two broad categories, altitude or vacuum effects, and atmosphere composition effects. At altitudes above 25,000 feet, the reduction of dielectric strength of air is appreciable and reaches its minimum at some point between 70,000 and 130,000 feet. In the latter range, switches that are dielectrically stable at sea level are prone to arc and produce a failure. At altitudes approaching 500,000 feet, contacting surfaces of nonhermetically sealed switches tend to become superclean because of the dissolution of surface films and oxides and molecularly bond "cold weld" together. Furthermore, the reduction of atmospheric pressure associated with increasing altitude promotes the outgassing of solvents and other volatiles that are entrained in the plastic components and other materials. These released volatiles may be reactive (corrosive) in nature or may accumulate as films on contact surfaces. Not to be overlooked is the possible synergistic combination of arc-created elemental gases with outgassing solvents resulting in degrading gaseous compounds. Effects on nonhermetic sealed switches resulting from atmospheric composition include increase in corrosion and/or film deposit on contact surfaces caused by the presence of moisture or other reactive substances in a gaseous form and explosion because of the presence of flammable compounds.

Transient Force Effects. The majority of switches used in aerospace applications are of the snap-action type. This design employs a spring to aid in the movement of the movable member and then secure it in its conducting/nonconducting position. Application of transient mechanical forces (shock and/or vibration) in excess of the design limit can overcome the inherent resistance to motion of the spring. The systems designer must not only be apprised of these design limits, but must also be cautioned against mounting the switch in such a manner as to magnify any transient forces that may be encountered in service. An example of the mechanical mounting that should be proscribed is cantilever mounting.

Current Application Effects. The current applied to a switch during all testing prior to end item use should be limited to the range that will be encountered in actual usage. Higher current levels cause increased heating, and can degrade the surface of the contact by creating carbon deposits and other films that the subsequent lower operational current levels of actual application cannot overcome.

Displacement and Frequency Limits. A review of the mechanical considerations used in design of switches will reveal that acceptable operation of the switch is dependent on two parameters of the operating force, plunger (or actuator displacement) and operational frequency. Loss of geometrical congruency between displacement requirements and movement generated by the applied force can result in malfunction and/or irreversible damage to the switch. Displacement beyond the inherent limits of the switch can result in bent or fractured contacts and/or other switch components. On the other hand, insufficient displacement can cause an apparent switch failure by failing to fully actuate the switch. Common causes of this type of problem is mismounting and thermal expansion mismatches.

The inertia of the moving components of the switch causes every switch to have a minimum operating time. Application of repetitive forces at higher frequencies than are defined by this operating time will result in apparent intermittent operation in that the switch will not respond to every force command.

Specification Parameters. The foregoing discussion has served to delineate application limitations of switches because of physical characteristics associated with their design and materials of construction. These limitations can be described as specification limits for use by manufacturers and using designers. Deviations from these limits can lead to failures.

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TYPICAL SUBMINIATURE SNAP-ACTION SWITCH DESIGN (FIGURE 12-1)

ITEM	ITEM NAME	MATERIAL OF CONSTRUCTION
19	Normally Open Stationary Contact	Fine silver
20	Normally Open Stationary Contact Terminal	Brass, 1/2 hard
21	Snap-Action Movable Contact Spring	Beryllium copper
22	Stationary Anchor	Brass, 1/4 hard
23	Common Terminal	Brass, 1/2 hard
24	Plain Washer	Brass, 1/4 hard
25	Actuator Bushing	Corrosion resistant steel
26	Ring Seal	Teflon
27	Plain Washer	Corrosion resistant steel
28	Lock Washer	Corrosion resistant steel
29	Ring Seal	Silicone rubber
30	Special Washer	Corrosion resistant steel
31	Actuator Spring	Chrome silicon steel
32	Switch Actuation Lever	Corrosion resistant steel
33	Switch Case	Molded glass filled phenolic plastic
34	Oval Head Rivet	Brass
35	Inert Gas Arc Weld	
36	Glass Seal	Glass
37	Header Tubes For Terminal Solder Joint	Glass seal alloy tubing with 60/40 solder
38	Leadwire Embedment	Moldable thermoplastic
39	Electrical Insulation	Extruded vinyl tubing
40	Contact and Ground Wires	Copper wire

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FLOW DIAGRAM				RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL		MANUFACTURING OPERATION	CRITICAL PROCESS	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
Switch Case Base With Terminals	17, 20, 23, 33	Clean and bake case	Removal of contaminants	C, D	A	A2; B1	
Movable Contact With Spring Anchors Stationary Contacts	11, 18, 19, 21, 22	Machine and assemble to base	Forming and positioning of contacts	D	C	A1, 3	
		Adjust and clean			A1		
Spring Plastic Plunger Case Cover	10, 12	Clean added parts, assemble, and check forces		D			
		Cobehn clean and reassemble	Removal of contaminants from contacts	A			
Sealing Epoxy		Seal and cure	Control of epoxy location	D		A2; B1	
		Mark and cure					
Actuator Bushing Seal Rings Plunger Washer	25, 26, 27, 29	Final inspect					
		Lubricate bushing and assemble	Amount of lubricant	D			
Guard	2	Press into assembly	Seating of guard			A1	
Actuator Plunger	1	Add to assembly and check movement	Fit of plunger			A1	
Inner Plunger Washer Seal Retainer Spring	3, 4, 7, 31	Assemble and hot stake	Degree of stake			A1, 3; B4	
		Seat spring	Location of spring			A1; B3	
		Lubricate	Amount of lubricant	D			
Spring	6	Assemble					
Bracket	8	Weld (35) bracket to bushing assembly	Weld parameters			A1, 3	
Actuation Lever Spring, Rivets	9, 32, 34	Assemble and rivet in two basic switches	Security of rivet			A1, 3	
Housing With Header Brazed On	13, 14, 36, 37	Adjust switch, assemble to housing and weld	Welding parameters	C, D	A, D	A1, 2, 3; B3	
Insulation Tubing Lead Wires Solder Preforms	39, 40	Add lead wires, solder, and add tubing	Soldering time and temperature	C	A	A3; B4	
		Flush, fill with dry nitrogen, pinch, and weld fill tube	Moisture content of nitrogen	A, E		A4; B4	
Lead Wire	40	Solder to fill tube stub	Soldering time and temperature	C	A		
		Sandblast terminal area and clean	Elimination of residual sand				
Guard	15	Degrease assembly and guard, add guard					
Lead Wire Embedment	38	Mask, pot (3 applications), and cure	Completeness of fill				
Paint	16	Clean, sandblast, paint, and add nameplate					
Nuts Washers	5, 28, 30	Add nuts and washers to assembly					
		Final inspection					
		Pack and ship					

NOTE: For items 1 through 40 see Fig. 12-1

Figure 12-2. Subminiature Snap-Action Switch - Typical Assembly Flow with Related Problem Codes

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TEST/EXAMINATION	PROCEDURE	WHEN FAILURE IS / LOOK FOR: RELATED PROBLEM CODES (see foldout in the Appendix)			
		OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
NONDESTRUCTIVE MECHANICAL					
External Visual Examination	Note all identifying markings and damage	C, D			all
Radiographic Inspection	If fixed focus X-ray is used, photograph in two or more orthogonal planes as required to record any anomalies within the device. If Vidicon (imaging) is used, examine and photograph anomalies as observed.	A, B, C	B, C, D	A1, 3; B3	
PROBLEM AREA VERIFICATION					
NONDESTRUCTIVE ELECTRICAL AND MECHANICAL	Measure and record static and dynamic electrical and mechanical characteristics as appropriate, such as Contact Resistance, Operate and Release Force, Operating Displacement, Dielectric Withstanding Voltage, etc.	all	all	all	
Seal Test (hermetics only)	Fine and Gross Leak Test	D		A2, 4; B1, 4	G, H
INDUCING FAILURES					
Special Conditioning	Baking, Temperature Cycling, and Vibration only if required to confirm problem area				
Electrical and Mechanical Measurements	Repeat appropriate static and dynamic mechanical and electrical characteristics testing and record changes				
PROBLEM CAUSE VERIFICATION					
Delidding	Remove case (carefully). Observe and record any anomalous conditions such as corrosion, particulate and film contamination, evidence of abnormal wear, or bent and broken parts	all	all	all	
Material Analysis Spectrographic Microprobe	Analyze all foreign materials not otherwise identifiable	D, E	A	A2, 3; B1, 2, 4	

Figure 12-3. Subminiature Snap-Action Switches - Typical Failure Analysis Flow with Related Problem Codes

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The metallic element actuator type most commonly used in the thermostatic snap-action switch is the bimetal snap-action disk which consists of two metals of different temperature coefficients laminated to form a single disk. The disk is formed in a curved shape and through carefully controlled processes is designed to instantaneously (by snap-action) change its curvature (concave to convex or convex to concave) at a discrete temperature. The switch contacts are opened and closed by the disk displacement. The switch contacts may be electrically isolated from the disk or the movable contact may be physically attached to the disk. The former electrically isolated design is preferred since it isolates I^2R heat generated by contact current flow from the disk providing closer temperature tolerance in the design.

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TYPICAL THERMOSTATIC SNAP-ACTION SWITCH DESIGN (FIGURE 12-4)

ITEM	ITEM NAME	MATERIAL OF CONSTRUCTION
19	Stationary Contact	Fine silver
20	Movable Contact	GP alloy on nickel
21	Insulator Bead	Steatite (AlSiMag #35)
22	Spring	Beryllium-copper, spring temper
23	Mounting Bracket	Cold rolled steel, ASTM A365-57T, nickel plated

NOTE: Not shown at mating point for Items 3 and 8

Adhesive: Locktite
81-31

FLOW DIAGRAM			RELATED PROBLEM CODES (see foldout in the Appendix)			
MATERIAL	MANUFACTURING OPERATION	CRITICAL PROCESS	OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
Movable Contact (20) Insulator Bead (21) Movable Arm (5)	Assemble and weld	Weld	A, B, C	A, C, D	A1, 3	
Stationary Contact (19)	Clean contact		D	A, C		
Connector(s) (10) Lead Wire (15)	Assemble and weld	Weld	C,	A, D		
Base (with retaining nut) (7) (8) Rivet (4)	Assemble and rivet contacts and connector to base	Rivet	A, B, C, D	A, C, D	A1, 3	
	Clean (ultrasonic)		D	A	A2; B1	
	Force check		A	C	A1	
Adjusting Screw (3) Disk (2)	Assemble					
	Calibrate				A1, 3; B3	
Adhesive	Secure calibrated adjustment	Control of adhesive (application area)	D		A3, B3	
Insulator (11) Cup (9)	Install insulator into cup and install base assembly	Installation of insulator and internal connectors	A	B, C, D	A2; B1	
Spring (22) Cover (1)	Install spring, add cover and weld cover to cup	Weld	B, D	A, D	A1, 2, 3; B1	
	Temperature check					
Terminal Extensions (18)	Seal (dry box)	Weld	D	A	A2; B1	G
	Leak check (oil)		D			E, F, G, H
	Leak test (Veeco)					E, F, G, H
	Plate	Plating process control	D			A
	Dielectric Test			A, D	A1, 2, 3; B1, 3	
	Insulation Resistance Test			A, D	A1, 2, 3; B1, 3	
	Clean and tin dip terminals	Plating process control				A
	Mark (electro-etch)					
	Final inspection (100% screen testing)					A, B, C, D, E, F, G, H
	Pack and ship					

Figure 12-5. Thermostatic Snap-Action Switch - Typical Assembly Flow with Related Problem Codes

TEST/EXAMINATION	PROCEDURE	WHEN FAILURE IS / LOOK FOR	RELATED PROBLEM CODES (see foldout in the Appendix)			
			OPEN I	SHORT II	PAR DEV III	MECH ANOM IV
NONDESTRUCTIVE MECHANICAL						
External Visual Examination	Note all identifying markings and external damage		C,D			all
Radiographic Inspection	If fixed focus X-ray is used, photograph in two or more orthogonal planes as required to record any anomalies within the device. If Vidicon (imaging) is used, examine and photograph anomalies as observed		A,B,C	B,C,D	A1,3	
PROBLEM AREA VERIFICATION						
NONDESTRUCTIVE ELECTRICAL AND MECHANICAL	Measure and record static and dynamic electrical and temperature characteristics as appropriate, such as Contact Resistance, Opening and Closing Temperatures, Temperature Differential, Dielectric Withstanding Voltage, etc.		all	all	all	
Seal Test (hermetics only)	Fine and Gross Leak Test		D		A2,4	G,H
INDUCING FAILURES						
Special Conditioning	Baking, Temperature Cycling, and Vibration only if required to confirm problem area					
Electrical and Mechanical Measurements	Repeat appropriate static and dynamic mechanical and electrical characteristics testing and record changes					
PROBLEM CAUSE VERIFICATION						
Delidding	Remove case (carefully). Observe and record any anomalous conditions such as corrosion, particulate and film contamination, evidence of abnormal wear, or bent and broken parts		all	all	all	
Material Analysis Spectrographic Microprobe	Analyze all foreign materials not otherwise identifiable		D,E	A	A2,3	

Figure 12-6. Thermostatic Snap-Action Switch - Typical Failure Analysis Flow with Related Problem Codes

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SWITCHES

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
8 MSFC-70-05	SHORT (including intermittents) Improperly routed leads	During system test of spacecraft, five fuses in ground support system burned out because of shorts within power transfer switch.	Investigation revealed that internal lead wires had been routed in such a manner that insulation was abraded from the lead to the switch motor brake. This resulted in a short between lead and motor housing.
9 MSFC-66-02	SHORT (including intermittents) Loose contact	During check-out of a rocket engine, a valve switch introduced erratic traces on an oscillograph recording.	Investigation revealed that the faulty switch contact was improperly swaged at its mounting point.
10 MSFC-68-21, 21A	SHORT (including intermittents) Loose or broken conductive part	During vehicle check-out, a 23 amp short was observed in the LOX vent and relief valve switch circuitry.	Analysis indicated the cause to be a failed weld joint of the internal switch actuating pin.
11 MSFC-69-04	PARAMETER DEVIATION - OPERATION AND RELEASE FORCE ANOMALIES Loose or defective parts	During functional test of a rocket engine, pressure switch actuated 125 psi below specified minimum.	Analysis revealed that the steel "U" frame in the switch was cracked. This crack was attributed to stress corrosion since 17-7 PH material is susceptible to stress corrosion.
12 MSFC-71-09, 09A	PARAMETER DEVIATION - OPERATING AND RELEASE FORCE ANOMALIES Defective parts	During cycling tests of ten toggle switches, one toggle lever failed to return to the maintain position.	Failure analysis performed on nine of the ten switches revealed that eight switches had broken contact pressure springs. Breakage was attributed to improper stress-relief annealing.
13 K9-71-07	PARAMETER DEVIATION - OPERATING AND RELEASE FORCE ANOMALIES Contamination	The switch's toggle arm would not move.	Examination showed the movable plastic slider was solidified to one side and the plastic had overflowed onto the metal indent, thus, preventing travel.
14 CK-A-72-01	PARAMETER DEVIATION - OPERATING AND RELEASE FORCE ANOMALIES Sticking	The lens assembly (pushbutton) was sticking.	Examination showed that worst tolerances made the mounting clips press too hard on the housing causing it to bow inward resulting in the lens assembly sticking.

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SECTION 13
VALVES
(GIDEP CODE 927)

13

INTRODUCTION

Objective. The objective of this section is to identify the major problems associated with the use of fluid valves and to provide approaches (developed from experience) for dealing with these problems.

General. Valves are used to control the flow of fluids, either liquids or gases, with respect to amount and direction. Industry employs many varieties of valves, such as gate, globe, poppet, plug, and needle valves, plus specialized varieties like check, metering, and relief valves. A common feature of all these valves is that they contain a solid movable member (gate, disk, poppet face, needle, or plug) that impinges on, or into an orifice in such a manner as to create a fluid-tight separation between the entry and outflow sections of the valve. The contacting surface of this orifice, i.e., valve seat, is normally of an elastomeric material. Where this is not true, the contacting surface of the movable member is deformable or elastomeric in nature or the seat is of a deformable material and the movable member is hard.

Problem Descriptions. The problems are first defined by use of specific examples cited in ALERT reports, and then by using a broader base from other government and industry investigations.

Problem Prevention. Problem prevention is dealt with by providing relevant information with respect to operational techniques, design limits, and inspection criteria.

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VALVES

PROBLEM AREA/ Cause	ALERT ITEM NO.	SUGGESTED ACTION
VALVE ELECTRICAL FAILURE Inadequate design	17	Design review
VALVE FAILED TO OPEN Interference from O-ring	18	Use O-rings made of material capable of withstanding the environment to which they are exposed.
VALVE BREAKAGE Inadequate design	19	Select valves so designed that there are no residual stresses introduced into the case during assembly; in-line construction is preferable.
SOLENOID FAILURE Inadequate design	20	Redesign the coils to eliminate the stress concentration point between the coil and armature hinge.

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DESIGN CRITERIA

General. Deterioration of the contacting surfaces, whether due to wear, damage during installation, chemical attack, misalignment, etc., will result in imperfect sealing resulting in internal leakage. All valves, with the exception of relief and check valves, are actuated by external mechanical force that is transferred to the movable member of a stem or riser. This actuating mechanism is subject to failure by seizure as the result of corrosion or contamination, or fracture. The required opening into the valve body for entry of the operating stem is an additional source of leakage, due to inadequate design and/or packing. As the valve body is generally formed from a casting, valves are subject to all of the hydrostatic problems associated with castings such as porosity and fracture from mechanical damage, or pressure stress fracture due to inadequate section thickness.

Valve Design Criteria. Primary consideration in the selections of valves includes knowledge of the physical property of materials from which the valve is manufactured in order to assure compatibility with: (1) applicable fluids, (2) operating temperatures and (3) pressure limits. The function the valve must perform and its dimesnional limitations are also important considerations. Life and wear factors must be taken into account as well as maintainability. The valve should be designed to facilitate replacement of gaskets, seals, and seat. The applicable limits that are the result of design consideration should be delineated at the design review that is conducted at time of first approval and should be confirmed by proof testing. Furthermore, these limits should be reflected in resulting specification and design handbooks as application notes in order that the system designer does not inadvertently contribute to premature failure of the finished system.

Major Problem Areas. A review of the "Problem Area/Cause and Suggested Action" summary will reveal that a majority of the problems can be controlled by design review procedures. Investigation of the ALERT report and the problem backgrounds, establish that the real problem is that the using designer has not, in many cases, been apprised of significant valve limitations. One of the fundamental aspects of initial design review of any part is to determine inherent usage limitations. Another significant problem area can readily be attributed to poor processing and control. A necessary part of initial review of a part that may be used in a critical application, is establishing a thorough knowledge of the manufacturer's processing and quality control methods.

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VALVES

ALERT[1] ITEM NO./ GIDEP NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
8 KSC-67-67, 67A	EXCESSIVE VALVE LEAKAGE Material incompatibility	After repeated subjection to sonic flow across valve seat, excessive leakage almost always occurs.	The high velocity (sonic) flow of gas across the valve seat erodes or blows out the valve seat which is a relatively soft plastic.
9 KSC-68-07	EXCESSIVE VALVE LEAKAGE Inadequate design	Gross leakage out of pilot plug valve.	Leakage caused by inadequate sealing of the poppet guide O-ring; believed to be design problem in the dimensioning of the poppet guide gland area that prevents application of sufficient sealing force on the O-ring.
10 ARC-69-03	VALVE INTERNAL LEAKAGE Damaged O-ring	Internal leakage was observed when valve was closed during system test.	Analysis revealed that the leakage was due to severe compressive set and nick in peripheral O-ring installed in valve stem. The compressive set was due to nonuniform loading and stretching in the groove. The nick was caused by the ring passing over an abrupt edge of the inlet port.
11 KSC 10-25-65	VALVE LEAKAGE Stress corrosion	Two valve fittings manufactured from 2024T351 aluminum were cracked and allowed hydraulic leakage into the system.	The cracks originated as a result of stress corrosion which was accelerated by the system operating pressure of 1500 psi.
12 F1-70-02	SOLENOID FAILURE Inadequate system design (mounting)	Armature of solenoid coil guide ring seized during vibration.	Seizure was caused by fretting and metal transfer that resulted from armature impacting against guide ring. The basic failure cause was amplification of system vibration due to inadequate mounting design and installation by the valve user. When securely mounted in the same system, the valve operated properly.
13 KCS-67-71	SOLENOID FAILURE Inadequate sealing	Solenoid valves fail during functional test prior to vehicle launch.	Analysis revealed evidence of moisture intrusion and rust deposits in solenoid enclosure and around solenoid actuator which inhibited valve action. Moisture intrusion points were identifed as improper O-ring seal on solenoid cover, poor seal around electrical connector/spacer-to-valve body, and solenoid mounting screws.
14 D7-69-2	SOLENOID FAILURE Contamination	During system acceptance test, valve failed to close.	Investigation uncovered a small particle lodged between the solenoid bore and movable armature. Source of particle was from a void in weld at bobbin/nonmagnetic end plate junction. Incomplete fusion of parent metal and weld filler form a cavity which traps metal chips that are subsequently dislodged during valve operation.

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SECTION 14
WIRE
(GIDEP CODE 951)

14

INTRODUCTION

OBJECTIVE

The objective of this section is to present summaries of wire related problems that have been documented on ALERT reports.

ORGANIZATION

The ALERT reports have been categorized into two major classifications: electrical wire and steel wire. Each summary shows:

1. Type of wire and the ALERT number as assigned by GIDEP.
2. The problem that was experienced, along with the cause of that problem.
3. A description of the manifestation of the problem.
4. An analysis of the events and circumstances which caused the problem.

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ELECTRICAL WIRE

TYPE; ALERT NO.[1] (GIDEP)	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
SILVER-PLATED COPPER MSC 7-7-67	IGNITION AND BURNING OF COPPER WIRES Conductive compounds across adjacent wires.	When glycol/water solution comes in contact with silver plated copper wires, under an applied voltage, conductive compounds form across adjacent wires causing localized incandescence and subsequent ignition and burning of copper wires.	At atmospheric conditions, silver plated copper wires subjected to dc electrical potential react chemically with glycol/water solutions. The reaction sequence is evidenced by: (1) bubbling (electrolysis), (2) discoloration, (3) sparking and incandescence. In 100 percent oxygen at 15 psia, the glowing and sparking will ignite the metal conductors and the electrical insulation.
SILVERCOATED COPPER, FLUORO-CARBON/ POLYIMIDE INSULATED K4-69-03	DIELECTRIC LEAKAGE Conductivity of the black outer dispersion coating.	Fluorocarbon/poly-mide insulated black wire was rejected because of insufficient surface insulation resistance.	If coating is in contact with center conductor and the outer insulation touches the structure or an adjacent wire (with the same condition) which is functionally grounded, there exists a high resistance path to ground (depending on conditions).
SILVER/SILVER COATED MSC-68-10	IGNITION OF WIRES WHEN DC CURRENT APPLIED Incompatibility of materials.	Silver or silver-coated wires impressed with a direct-current potential reacted chemically with glycol/water solutions to produce ignition when silver is the positive terminal. At a minimum potential of 1.55 volts dc in air and in 100 percent oxygen, silver circuitry in glycol/water solutions produced smoke and fire.	When a dc current is applied to silver or silver-coated wires, where silver is the positive terminal and glycol/water solutions are present, silver hydroxide may form. Presence of a silver chelating agent, benzotriazole (BZT), inhibits the formation of silver hydroxide. Pure copper, nickel covered copper, or tin-plated wires do not have the same reaction with glycol/water and do not create a flammability hazard under these conditions.
THERMORAD, POLYOLEFIN INSULATED MSC 4-13-65	DENTED AND SEVERED BRAIDED-SHIELD Damage during rework.	The shield on the 20 gauge "Thermorad" (TRT) polyolefin insulated wire was found to be damaged the full length of the shield. The damage ran parallel to the conductor and varied from a slight indentation to a cut completely through the shield.	Manufacturer's failure analysis indicated that the wire had been reworked prior to shipment. In process of rework, the shield was damaged prior to fabrication of the outer polyolefin jacket. Subsequent inspection failed to detect the damage because the outer polyolefin jacket obscured the damaged shield.

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STEEL WIRE

TYPE; ALERT NO.[1] (GIDEP)	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
7/8 INCH, 18 STRAND KSC-70-01	BROKEN CABLE Corrosion	Hoisting cable (high carbon type AISI 1085 steel) designed for minimum proof-load of 26,800 pounds broke at less than 10,000 pounds while being proof-tested to 15,600 pounds. Cable had passed proof test at 26,800 pounds about a year previously.	Examination showed that the cable had rusted along its length and the fractured ends were badly corroded. The effective area of most wires had been substantially reduced and the sound metal had been reduced 75 percent. Many wires were completely corroded to a point at the tip, indicating they were separated by corrosion prior to the proof test. Cable exposed to corrosive environments should be periodically inspected and lubricated.

NOTE:
1. Where no ALERT number (GIDEP) exists, the originator and date are shown.

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SECTION 15
MISCELLANEOUS

15

INTRODUCTION

OBJECTIVE

The objective of this section is to present summaries of problems on miscellaneous devices that have been documented on ALERT reports.

ORGANIZATION

The ALERT reports have been categorized into the major GIDEP classifications for parts, components, and materials. Each summary shows:

1. Major classification, GIDEP code, and ALERT number as assigned by GIDEP.

2. The problem that was experienced, along with the cause of that problem.

3. A description of the manifestation of the problem.

4. An analysis of the events and circumstances which caused the problem.

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MISCELLANEOUS

MAJOR CLASS; GIDEP CODE/ ALERT NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
BOARDS, PRINTED WIRING 142 KR 5-1-67	LOW RESISTANCE PATHS Graphite marking pencils	Defective solder connections on printed circuit boards being marked with graphite pencils.	Low resistance paths formed between conductive patterns and remained after rework and cleaning.
COILS, INDUCTANCE 181 GSFC-70-02	OPEN Defective weld connection	Three inductors were found to be open-circuited during module fabrication, and four were found to be intermittently open-circuited during incoming inspection.	Failure analysis revealed that all seven inductors failed because of defective weld connections between the inductance (coil) wires and the external lead wires.
COILS, INDUCTANCE 181 GSFC 9-1-67	OPEN Broken wire	A filter network malfunctioned at temperatures below +40°C and operated normally above +40°C.	Examination revealed the inductor was open-circuited because of taut terminal leads pulling against sharp internal bends. This reduced the ability of the wire to withstand dimensional stresses occurring during thermal cycling.
COILS, INDUCTANCE 181 D7-A-72-01	OUT OF SPECIFICATION Inadequate processes and quality control	Leads improperly supported by encapsulant which could lead to separation of intenal toroid lead due to fatigue.	Investigation revealed fault due to improperly applying compound after attachment of leads preventing adherence of encapsulant to leads.
COMPUTER AND RECORDING ELEMENTS 191 GSFC-70-01	DESTRUCTION OF TAPE REEL Breakage of tape seal	Tape reels are destroyed when they fall to the floor because the tape seals (by which the reels are hung) break.	Hanging of the tape reels for extended periods of time leads to breakage of the tape seal at the square cutout in which the hangar clasp fits.
COMPUTER AND RECORDING ELEMENTS 191 KSC-69-08	POOR DURABILITY OF MAGNETIC TAPE Tape slows down and becomes sticky after many passes through transport	Tape exhibited poor durability when operated many times on the transport. There was a visible slowing down of the tape and it became very sticky.	A test was developed which exercised a small portion of tape on the transport. Three-quarters of these tapes tested failed prior to 1000 passes, whereas, comparable tapes exceeded 10,000 passes.
CRYSTALS 241 K9-71-13	NO OSCILLATION Short	Module failures traced to crystals that had stopped oscillating.	Investigation revealed crystals were cocked and shorted to can. Manufacturer had not used internal Teflon shield to prevent shorting to the can. Cocking attributed to poor workmanship.

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MISCELLANEOUS

MAJOR CLASS; GIDEP CODE/ ALERT NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
FILTERS, ELECTRICAL 321 GSFC-70-14	OPEN Broken connection	Attenuation of the input signal at resonant frequency did not differ significantly from attenuation at frequencies above or below resonance on filters.	Failure was attributed to fractured spring wire, or separation of the wire from the resonator.
FILTERS, ELECTRICAL 321 E1-71-01	OPEN Broken connection	Internal lead wire of filter coil broke from stud assembly after box post-vibration test.	Compound to hold coil in place was soft, had cracks, and of insufficient amount, which apparently allowed coil to move during vibration which cold worked coil lead. Also, internal design had been changed from a retaining bead to a nonretaining straight post terminal.
FILTERS, ELECTRICAL 321 GSFC-72-01	SHORT Solder reflow	Filter was found shorted to ground after installation in inertial guidance system equipment.	Investigation revealed that a mass of solder had shorted the internal feed-through to the case, apparently resulting from reflow into the case from the eyelet solder seal during installation soldering of filter.
FILTERS, NON-ELECTRICAL 325 MSC-A-72-02	LEAKAGE Corrosion	Oil filter leaked oil.	Investigation revealed a small hole near the base of the filter. Removal of the filter housing disclosed internal corrosion where the steel filter element spring rests against the aluminum base. Cause of the failure was galvanic action between dissimilar metals.
FINISHES AND SURFACE TREATMENTS 331 MSFC-70-04	OPEN Debonded diode solder connection	A printed wiring board module exhibited an intermittent failure.	Failure was caused by an electrical separation between the solder and copper pad at a diode solder connection. The module board had been gold plated and displayed high heat concentration (up to 195°F) in the area of the failed solder joint. Tests showed Udylite Bright Acid Copper (UBAC), used in copper plating, was responsible for the debonding.
FINISHES AND SURFACE TREATMENTS 331 K9-A-72-09	POOR ADHESION OF ELECTROPLATING Inadequate processes and quality control	The use of cold (below 60°F) rinse waters subsequent to electroless copper deposition can cause poor adhesion of subsequent copper electroplating deposited from high acid copper content solutions because of residual alkali.	No problem is evidenced if alkaline copper electroplating solutions are used. Manufacturer recommends that rinse waters be above 60°F or that electro cleaning be used to prepare surface for the electroless deposit.

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MISCELLANEOUS

MAJOR CLASS; GIDEP CODE/ ALERT NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
GENERAL TECHNICAL DATA 347 ARC-69-01	FORMATION OF TOXIC GASES Incompatibility of materials	Testing of biosatellite capsule was interrupted when the small monkey (payload) became ill.	Cause of illness was the presence of dichloroacetylene gas in the capsule. The gas source was traced to the presence of halogenated hydrocarbons, one of which was trichloroethylene. The toxic gas is generated when trichloroethylene is in combination with usual capsule atmospheres; lithium hydroxide (used to reduce carbon dioxide), heat, and metabolic products of water vapor and carbon dioxide.
GENERAL TECHNICAL DATA 347 MSFC-70-07, 07A	FORMATION OF HYDROCARBONS Incompatibility of materials	Surfaces treated with Freon showed presence of hydrocarbons.	Development of a system for testing hydrogen in metals disclosed one source to be Freon 113 which was stored in polyethylene bottles. Investigation revealed that Freon 113 leaches hydrocarbons from polyethylene containers.
GENERAL TECHNICAL DATA 347 T6-A-72-02	WATER SAMPLER FAILED Shorted switch	Water sampler failed to operate when received.	Investigation revealed water in the stepping switch housing had shorted out the switch.
GYROS 358 LeRC-68-01	WRONG AXIS INSTALLATION Location pins not securely fitted in gyro flange	A number of gyros have been installed in the wrong axis because of pins slipping during installation.	Gyro locating pins are press fitted into the gyro flange and can be pushed back during installation without being detected. If the pins are pushed back prior to installation, the locating reference is lost and the gyro can be installed in the wrong axis.
GYROS 358 MSFC-69-05	FAILURE TO START Lubricant breakdown	Of nine rate gyros taken from an eleven month storage period, one wheel failed to start.	Investigation revealed spin bearing lubricant destruction from heat and contamination. The cause was found to be improper heat sinking at the time the gimbal was originally sealed (welded).
HARDWARE 361 KSC-70-03	LINEAR CRACKS IN CLAMPS USED ON LOX SYSTEM Material incompatibility	Galvanic corrosion set in due to the potential difference between graphite and stainless steel (>1.5 volts).	Tests disclosed that stress corrosion occurred primarily due to galvanic action of graphite on 19-9DL stainless steel, after a 30 day exposure.
HARDWARE 361 KSC 5-4-66, MSFC-66-03	BROKEN SPRING Marginal design	Bailatch handle assembly latching springs broke in several assemblies after only a few operations.	Tests proved the spring was a marginal design with a mean operating life of 140 cycles at maximum deflection, with a range from 1 to 306 cycles.

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MISCELLANEOUS

MAJOR CLASS; GIDEP CODE/ ALERT NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
HARDWARE 361 MSC-71-03, 03A	DEFECTIVE ACTUATION SHAFT Inadequate crimping or swaging	End cap swaged on the end of the activation shaft of quick release pin pulled off during a training demonstration.	Investigation revealed cause of failure due to inadequate crimping or swaging of the end cap.
HOSE 404 MSFC-67-11	CRACKED LINES Overaged material	A fuel pump balance cavity return line (conductive Teflon covered with wire braid) leaked during a gas pressure test. The line had undergone one 30 psi test, three 80 psi tests, and failed at 10 psi on the fifth test.	Failure is attributed to overaged material caused by high oven temperature control limit and inconsistent flow through the oven.
HOSE 404 MSFC-68-14	FLEX HOSE FAILURE Resonant flow-induced vibrations	Analysis of flight data indicated a failure of a flex hose assembly carrying liquid hydrogen.	Flow testing at sea level of these hoses carrying cryogens may be inadequate for hoses which are to be operated in a vacuum. Flow-induced vibrations at sea level are dampened by the formation of liquid air around the hose bellows. Results to date indicate that, under vacuum conditions, resonant flow-induced vibrations are of an amplitude sufficient to cause a line failure.
HOSE 404 MSC-71-06	HOSE FAILURE Improper hardness and dimensions	Oxygen umbilical hose on astronaut life support assembly failed.	Mechanism of failure determined to be soft tubing and an oversized hole in attaching nut, the combination permitting extrusion of tubing flare through nut creating a galled condition.
IDENTIFICATION DEVICES AND METHODS 411 KSC-69-01	CRACKED STAMP CAPS Improper O.D. dimensions of holder	Cracked stamp caps, which contain the ink pads, impaired the use of inspection stamps.	Problem was caused by the holders which had not been tumbled to meet proper O.D. dimensions.
INSTRUMENTS AND CONTROLS 428 KSC 4-25-66	LEAK Lack of seal	Bourdon tube tip leaked after one year service.	Failure analysis revealed: (1) Steel ball which serves as seal and heat sink for braze at tip of Bourdon tube was missing; (2) Highly porous braze seal.
INSTRUMENTS AND CONTROLS 428 C6-70-01	OPEN Broken coil lead	Alpha/numeric magnetic indicator failure.	Failure was caused by breakage of the common coil lead at the solder connection to the terminal. The lead had insufficient stress relief.

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MISCELLANEOUS

MAJOR CLASS; GIDEP CODE/ ALERT NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
LIGHT SOURCES, ELECTRICAL 461 FH-71-01, 01A	INTERMITTENT OPERATION Improper swaging	Terminal produces loose-tooth effect resulting in intermittent operation.	Investigation revealed intermittent operation resulted from improper swaging.
LIGHT SOURCES, ELECTRICAL 461 FH-72-01, 01A	OUT OF SPECIFICATION Inadequate processes and quality control.	Manufacturing discrepancies precluded use of lamps.	Failure analysis revealed: (1) Varying amount of solder on contact bases, (2) Lamps too short to make proper contact in all light assemblies, and (3) MS25237 does not specifically control minimum dimensions for over-all length of bulb.
LIGHT SOURCES, ELECTRICAL 461 FH-A-72-02	MECHANICAL ANOMALY Incorrect terminal identification	Terminals incorrectly identified; i.e., No. 1 "Line" terminal should be No. 2 "Ground".	Terminal No. 1 is grounded to frame (hood), presenting an arcing possibility which could create a personnel as well as a fire and explosion hazard.
LUBRICANTS 484 MSC 11-1-66	EXPLOSION HAZARD Incompatibility of materials	Aluminum parts have been lubricated with halogenated hydrocarbon oils and greases.	Chlorfluorocarbon oils and greases, and other halogenated hydrocarbon lubricants can ignite explosively under conditions of hi-shear involving aluminum. Fluorosilicone based lubricants can be used with aluminum without any known hazards.
LUBRICANTS 484 MSFC-68-11	SENSITIVITY VARIATION Incompatibility of materials	Lubricant exhibited variation in its sensitivity to contact with LOX.	Problem was caused by a change in the formulation (Teflon base to fluorinated silicone).
LUBRICANTS 484 MSFC-71-18	BEARING FAILURE Incompatibility of materials	A bearing failed due to galling.	After manufacture, bearing was lubricated with a dry lubricant and silicone oil applied over the dry lubricant for general corrosion protection. The oil is not compatible with dry film lubricants.
MECHANISMS, POWER TRANSMITTAL 511 KSC-70-12	FAILURE OF CABLE Improper swaging	Hoist cable (carrying valid inspection stickers) came loose from drum, allowing load to fall.	Investigation indicated ball end (MS20664) had never been swaged to the cable end to retain the cable to the drum. Cable was evidently held in place in the cable boss by a set-screw until failure occurred.
MOTORS AND MOTOR GENERATORS 532 LeRC-67-33	NOISY OPERATION Improper assembly	Motor in Centaur timer package exhibited noisy operation.	Failure analysis disclosed improperly installed output shaft thrust bearing assemblies (parts interchanged). Many units did not meet the required 0.001 inch minimum clearance between thrust plate and shaft.

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MISCELLANEOUS

MAJOR CLASS; GIDEP CODE/ ALERT NO.	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
POWER SUPPLIES 562 B8-A-72-01	LOW OUTPUT VOLTAGE Incorrect internal wiring	Output voltage was low at rated load.	Investigation revealed one capacitor was not wired, and two capacitors were interchanged.
POWER SUPPLIES 562 MSFC-A-72-10	POLARITY REVERSAL Source voltage interruption	Power supply output reversed polarity causing failure of other components.	Investigation revealed that the inherent design of the power supply caused output polarity reversal whenever the source voltage was interrupted.
POWER SUPPLIES 562 GSFC-A-72-01, GSFC-A-72-03	PADDLE FAILURE Insufficient solder at tab-cell joint	Solar array paddle showed 200 lifted tabs after two-cycle thermal acceptance test.	Cause was tentatively identified as having less than 50 percent solder fillet visible on 60 to 70 percent of the tabs on each paddle.
POWER SUPPLIES 562 GSFC-72-05	POWER SUPPLY FAILED Malfunction of overvoltage protection circuit	Power supplies failed as a result of a malfunctioning overvoltage-protection circuit.	Three failures were characterized by intermittent loss of output voltage which later restored itself. Four of the failures caused the output voltage to pulsate with some periodicity.
PUMPS AND HYDRAULIC MOTORS 575 KSC-70-02, 02A	BEARINGS FAILED Insufficient lubrication	A LOX pump failed during vehicle countdown demonstration test.	Failure of the pump thrust and radial bearings was caused by insufficient lubrication. The oil level was maintained too low because of an improperly placed "full" mark.
REGULATORS, FLUID 597 MSFC-70-08	OUT OF SPECIFICATION Undersize weld joints	Welds joining inlet and outlet connections to regulator body were undersize.	Measurement of the welds did not meet minimum requirements established by the manufacturer and do not provide the required 4 to 1 burst protection.
REGULATORS, FLUID 597 KSC-69-02, 02A	EXCESSIVE LEAKAGE Hard and brittle O-rings	Leakage was detected when the regulator was pressurized to 3000 psig.	Examination revealed that the adapter O-ring was grossly extruded and had lost all of its resiliency. Amber colored rings (a polyester type polyurethane) take on a hard set, become brittle, and chip. Black colored rings (a Buna-N formulation) lose their elasticity, turn putty-like, and often disintegrate.
REGULATORS, FLUID 597 KSC-69-14, 14A, 14B, 14C	FLASH FIRE Incompatibility of materials	Flash fire occurred in the high pressure side of an oxygen type resuscitator.	Cause was attributed to oxygen incompatible materials such as 6/6 nylon, Buna-N O-rings, neoprene seats, and cotton thread.

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MISCELLANEOUS

MAJOR CLASS; GIDEP CODE/ ALERT NO.[1]	PROBLEM AREA/ Cause	PROBLEM DESCRIPTION	PROBLEM ANALYSIS
TUBING, CASINGS, AND SLEEVING 921 MSC-68-08	METAL DAMAGE Intergranular corrosion	Extensive metal damage occurred on the OD of aluminum tubing.	Damage was due to intergranular corrosion and bare spots in the blue anodic coating. Bare spots were caused by improper manufacturing process. Intergranular corrosion was due to packaging procedures.
TUBING, CASINGS AND SLEEVING 921 MSFC-71-08	INSUFFICIENT HARDNESS Improper processing	A286 stainless steel sleeves did not meet Rockwell range of C36-C45 hardness.	The cause of this deficiency was attributed to improperly processed raw material.
TUBING, CASINGS AND SLEEVING 921 MSFC-71-20, 20A	IMPROPER PROCESSING Stains and pitting	Stains and pits up to 0.007 inches found on inside surface of stainless steel tubing.	Investigation revealed that this condition was caused by inadequate control of pickling, rinsing, and/or drying procedures during manufacture.
WAVEGUIDE AND MICROWAVE COMPONENTS 941 E9-69-09, 09A	HIGH ATTENUATION AND VSWR Intermittent contact	Coaxial line attenuators with BNC connector showed greater attenuation than marked and high VSWR.	Investigation disclosed intermittent contact between the body of the assembly and the connector. Expoxy, used to hold the connector in contact with the shell of the coaxial return cylinder, insulates parts from each other.

NOTE:
1. Where no ALERT number (GIDEP) exists, the originator and date are shown.

APPENDIX A

A

PROBLEM CODES AND DEFINITIONS		
PROBLEM CODE		**DEFINITION**
AREA	**CAUSE**	
I		OPEN (low capacitance and in-spec dc leakage)
	A	Lead Separation
	B	Discontinuous Plates
	C	Termination Metallization Separation
	D	No Contact With Plates
	E	Inadequate Cathode Connection
II		SHORT (extremely high dc leakage/low insulation resistance)
	A	Conductive Material Bridging Dielectric (internal)
	B	Conductive Material, External (e.g., silver)
	C	Deformed Plates (nonuniform thickness)
	D	Breakdown of Dielectric
	E	Nonuniform Structure of Anode Slug
	F	Loss of Hermeticity
	G	Internal Conductive Bridging Under Vibration
	H	Inadequate Capability for Thermal Expansion of Electrolyte
III		ELECTRICAL PARAMETER DEVIATION (high or low)
	A	Capacitance
	1	Lead termination problems
	2	Dielectric materials/processing, uncontrolled
	3	Dielectric thickness variation
	4	Low plate area
	5	Cracked plates
	6	Deformed plates
	7	Nonuniform plate stacking
	8	Nonuniform structure of anode slug
	B	DC Leakage/Insulation Resistance
	1	Cracked plates
	2	Conductive material bridging dielectric (internal)
	3	Conductive material (external)
	4	Deformed plates
	5	Breakdown of dielectric
	6	Nonuniform plate stacking
	C	Dissipation Factor/Equivalent Series Resistance
	1	Lead termination problems
	2	Internal metal bonding poor
	3	Metal plate discontinuities
	4	Nonuniform structure of anode slug
	D	Temperature Coefficient of Capacitance
	1	Dielectric materials/processing uncontrolled
IV		EXTERNAL MECHANICAL ANOMALY
	A	Poor lead plating
	B	Case dimensions
	C	Lead spacing
	D	Encapsulant on leads
	E	Damaged leads
	F	Cracked case
	G	Salt on outer seal surface
	H	Defective hermetic seal
	I	Improper marking

Figure 3-12. Problem Codes and Definitions

This foldout table is required for use with Figures 3-2 (p 3-16), 3-3 (p 3-18), 3-6 (p 3-26), 3-7 (p 3-27), 3-8 (p 3-29), 3-10 (p 3-34), and 3-11 (p 3-36).

This foldout table is required for use with Figure 4-2 (p 4-11).

PROBLEM CODES AND DEFINITIONS		
PROBLEM CODE		DEFINITIONS
AREA	CAUSE	
I		OPEN (including increased resistance)
	A	Defective Component
	B	Incorrect Part Used
	C	Contamination
	D	Installation Procedure
	E	Missing Part
	F	Inadequate Design
	G	Incorrect Part Dimensions
	H	Process Out of Control
II		SHORT
	A	Contamination (including moisture)
	B	Broken Part
III		ELECTRICAL AND MECHANICAL PARAMETER DEVIATION
	A	Loss of Hermeticity
	1	Bond failure
	B	Low Retention Force
	1	Defective component
	2	Manufacturer testing
	C	Excessive Mating Force
	1	Process out of control
	D	Polarity Reversal
	1	Specification error
	E	Connector Comes Apart
	1	Inadequate design
	F	Excessive RF Leakage
	1	Inadequate design
IV		MECHANICAL DAMAGE
	A	Corrosion
	B	Incorrect Part Dimension
	C	Chemical Attack
	D	Inadequate Design
	E	Process Out of Control
	F	Cracked, Bent, or Broken Components
	G	Installation Methods
	H	Broken Leads

Figure 4-3. Problem Codes and Definitions

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This foldout table is required for use with Figures 6-2 (p 6-12, 6-13) and 6-3 (p 6-15)

PROBLEM CODES AND DEFINITIONS

PROBLEM CODE AREA	PROBLEM CODE CAUSE	DEFINITION
I		OPEN including increased resistance)
	A	Deformed Contacts
	B	Loose or Broken Contacts, or Break in Element
	C	Termination Separation
	D	Contamination (film or particulate)
	E	Contact, Element or Terminal Corrosion
	F	Cracked Substrate
	G	Improper Positioning of Parts
	H	Latching Difficulty
II		SHORT (including intermittents)
	A	Conductive Contamination
	B	Misrouted Internal Leads
	C	Deformed Contacts
	D	Loose or Broken Conductive Parts
	E	External or Internal Conductive Bridging
	F	Design Deficiency
III		PARAMETER DEVIATION
	A	Operating and Release Force Anomalies – Electrical Operation
	1	Mechanical misalignment
	2	Contamination (film or particulate)
	3	Loose or defective component parts
	4	Excessive contact wear, contact, element or terminal corrosion
	5	Inability to latch
	6	Undesirable tripping
	B	Operating Displacement (plunger or activating mechanism travel)
	1	Contamination (film or particulate)
	2	Inadequate heat treatment
	3	Loose or defective parts
	4	Excessive contact corrosion
	C	Cracked Substrate
IV		EXTERNAL MECHANICAL ANOMALY
	A	Poor Terminal Plating
	B	Case Dimensions
	C	Termination Spacing
	D	Encapsulant on Terminals
	E	Damaged or Loose Terminals
	F	Cracked or Damaged Case
	G	Defective Hermetic Seal
	H	Cracked Terminal Beads (on hermetic devices)
	I	Contamination

Figure 6-4. Problem Codes and Definitions

This foldout table is required for use with Figures 10-2 (p 10-16, 10-17), 10-3 (p 10-19), and 10-4 (p 10-24).

PROBLEM CODES AND DEFINITIONS		
PROBLEM CODE		DEFINITION
AREA	CAUSE	
I		FAILURE OF CONTACTS TO MAKE OR BREAK
	A	Contamination
	B	Armature Binding
	C	Open Coil Winding
	D	Shorted Coil Winding
	E	Deformed Parts
	F	Fractured Actuator Arm
	G	Improper Armature/Pole Alignment
	H	Oversize/Undersize Parts
	I	Fused Contacts
	J	Thermal Stress
II		SHORT
	A	Contamination
	B	Fused Contacts
	C	Shorted Terminals
	D	Shorted Coil
III		ELECTRICAL PARAMETER DEVIATION
	A	Contamination
	B	Defective Insulation
	C	Incorrect Contact Gap
	D	Improper Lead Positioning
	E	Contact Pressure
	F	Organic Outgassed Products
	G	Plated Contact Surface Defects
	H	Improper Backfill (too dry, or contaminated)
	I	Friction on Armature
	J	Loss of Mercury
IV		MECHANICAL ANOMALY
	A	Cracked Terminal Leads
	B	Cracked Glass Beads in Header or Body
	C	Dents in Case
	D	Poor Terminal Plating
	E	Improper Tolerances
	F	Resonant Points (enclosure, contacts)
	G	Contact Overtravel
	H	Insufficient Actuator Bead Gap
	I	Improper Mounting

Figure 10-5. Problem Codes and Definitions

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This foldout table is required for use with Figures 11-5 (p 11-22), 11-6 (p 11-23), 11-7 (p 11-24), 11-8 (p 11-25), and 11-9 (p 11-27, 11-28).

PROBLEM CODES AND DEFINITIONS		
PROBLEM CODE		DEFINITION
AREA	CAUSE	
I		OPEN
	A	Broken Resistive Element
	B	Fractured Ceramic Substrate
	C	Contamination
	D	Inadequate Wiper Contact (for variable resistors)
	E	Lead Separation
	F	Galvanic Corrosion
	G	Corona Discharge
	H	Metal Termination Separation
	I	Cracked or Broken Tabs
II		SHORT
	A	Bridging of Element Turns
	B	Corona Discharge
	C	Contamination
III		ELECTRICAL PARAMETER DEVIATION
	A	Out of Tolerance (increase)
	1	Contamination
	2	Loss of hermeticity
	3	Inadequate fit of metal cap
	4	Loss of element cross section
	5	Excessive electrical noise
	B	Out of Tolerance (decrease)
	1	Reduction of element oxides
	2	Electrostatic charge
	3	Faulty wire insulation
IV		MECHANICAL ANOMALY
	A	Poor Epoxy Bonds
	B	Poor Lead Plating
	C	Case Dimensions
	D	Damaged Leads
	E	Cracked Case

Figure 11-10. Problem Codes and Definitions

This foldout table is required for use with Figures 12-2 (p 12-15), 12-3 (p 12-17), 12-5 (p 12-23), and 12-6 (p 12-25).

		PROBLEM CODES AND DEFINITIONS
PROBLEM CODE		DEFINITION
AREA	CAUSE	
I		OPEN (including increased resistance)
	A	Deformed Contacts
	B	Loose or Broken Contacts
	C	Termination Separation
	D	Contamination (film or particulate)
	E	Contact Corrosion
	F	Insufficient Contact Pressure
II		SHORT (including intermittents)
	A	Conductive Contamination
	B	Misrouted Internal Leads
	C	Deformed Contacts
	D	Loose or Broken Conductive Parts
III		PARAMETER DEVIATION
	A	Operating and Release Force Anomalies
	1	Mechanical misalignment
	2	Contamination
	3	Loose or defective component parts
	4	Excessive contact corrosion or wear
	5	Sticking
	B	Operating Displacement (plunger or activating mechanism travel)
	1	Contamination
	2	Inadequate heat treatment
	3	Loose or defective parts
	4	Excessive contact corrosion or wear
IV		EXTERNAL MECHANICAL ANOMALY
	A	Poor Terminal Plating
	B	Case Dimensions
	C	Termination Spacing
	D	Encapsulant on Terminals
	E	Damaged or Loose Terminals
	F	Cracked or Damaged Case
	G	Defective Hermetic Seal
	H	Cracked Terminal Beads (on hermetic devices)

Figure 12-7. Problem Codes and Definitions

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KEYWORD INDEX

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